The Effects of an Intermittent Piped Water Network and Storage Practices On Household Water Quality in Tamale, Ghana

By

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Abstract

The United Nations Millennium Development Goals include a target to halve the number of people without access to "improved" water sources, which include piped water supply. However, an "improved" source of water does not necessarily indicate a safe source. The city of Tamale in northern Ghana has a piped water network that supplies treated water, but the system is intermittent and many users only have access to piped water several days per week. In order to have sufficient supply of water, users are forced to store large quantities of water in their homes, sometimes in unsanitary storage containers.

Samples taken from households around Tamale indicate that there is widespread contamination of drinking water as indicated by total coliform, *E. coli*, and lack of chlorine residual. Examination of data from Ghana Water Company Limited, the local utility shows that water quality is being degraded between the treatment plant outlet and use by households. This degradation could be caused by low-pressure situations in the intermittent distribution system, allowing contaminants to enter the system. The contamination could also be caused by unhygienic water storage practices in the home, such as storing water in open containers and dipping unwashed hands into the water supply. Interviews conducted in 40 households show that many households do not practice hygienic water storage and handling.

In the short term, it is recommended that local NGOs or local government agencies increase efforts to educate users about proper water handling and storage practices to decrease bacteriological contamination of drinking water in the home. In the long-term, it is recommended that the intermittency of the system be decreased by improving maintenance on pipelines and removing illegal connections.

Thesis Supervisor: Susan Murcott
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Abbreviations and Acronyms

APHA	American Public Health Association
AWWA	American Water Works Association
CDC	Center for Disease Control
CFU	Colony Forming Units
DALY	Disability Adjusted Life Years
DMA	District Metered Area
GIS	Geographic Information Systems
GPM	Gallons Per Minute
GWCL	Ghana Water Company Limited
HWTS	Household Water Treatment and Safe Storage
ISO	International Standards Organization
M.Eng	Master of Engineering
MGD	Million Gallons per Day
MIT	Massachusetts Institute of Technology
MLD	Million Liters per Day
MPN	Most Probable Number
NRW	Non-Revenue Water
PAHO	Pan-American Health Organization
PHW	Pure Home Water
PSI	Pounds per Square Inch
SDWA	Safe Drinking Water Act
SSNIT	Social Security and National Insurance Trust
SWMM	Storm Water Management Model
US EPA	United States Environmental Protection Agency
USAID	United States Agency for International Development
WEF	Water Environment Federation
WHO	World Health Organization
WSP	Water Safety Plan
WTP	Water Treatment Plant

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* All photos are credited to the author unless otherwise noted

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1. Introduction

1.1. Global Water Supply

According to the latest reports from World Health Organization (WHO)/UNICEF, in 2010 more than 780 million people worldwide lacked access to improved drinking water (UNICEF, WHO 2012). The WHO defines "improved" drinking water sources as any sources that are "by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with fecal matter."[1] Through their "Water Ladder" framework, the WHO/UNICEF lists a piped water connection, either in the home or a public area at the top of the ladder in terms of an improved water source.

Figure 1–1: Drinking Water Ladder[2]

However, this definition does not necessarily mean that people with access to "improved" water sources are drinking safe water (i.e., water that is free of waterborne pathogens or other disease-causing contaminants). In fact, many studies have shown unsafe levels of bacteriological contamination in household drinking water, even when that water is supplied from an "improved" source (Wright, Gundry, et al. 2004). This contamination can be caused by any number of problems, from source water contamination, to unsanitary taps, to problems within the piped system, and problems with household storage.

1.2. Two Causes of Water Contamination

This research will focuses on two specific causes of water contamination – intermittent piped water networks and unsafe household storage.

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[1] http://www.wssinfo.org/definitions-methods/ accessed on April 2, 2013

[2] Source: http://www.wssinfo.org/definitions-methods/watsan-categories/

1.2.1. Intermittent Piped Water Networks

An intermittent piped water network is one where water does not flow continuously to customer homes or public taps. Instead, water flows only intermittently, anywhere from several hours a day to only once a week or even once a month in extreme cases. Intermittent water supplies are found all over the developing world. It is estimated that one third of urban water supplies in Africa operate intermittently (Lee and Schwab 2005). Intermittent water supplies are caused primarily by lack of sufficient water to serve all customers and keep the piped networks fully pressurized at all times. If water is scarce, in order to deliver water at adequate pressure in one neighborhood, water may need to be routed away from other neighborhoods. Intermittency can be caused by scarcity of source water, scarcity of treatment capacity, intermittency of electricity to run water pumps, high leakage rates, high population growth, or some combination of these conditions.

Intermittent piped water networks can lead to contamination of otherwise safe water supplies due to back-pressure conditions in the system. Back-pressure conditions are present when the water in the piped network is at a lower pressure than surrounding (potentially contaminated) water, such as rainwater, sewage spills, latrine drainage, etc. This contaminated water is able to infiltrate the piped network through small leaks and cracks due to the outside water pressure being greater than the water pressure within the pipe. Because of this risk, many American state regulatory agencies require a minimum pressure to be maintained in the distribution system. The Water Distribution Systems Handbook developed by the American Water Works Association (AWWA) recommends a minimum pressure of 20 psi be maintained to prevent contamination (Mays 2000).

1.2.2. Household Water Storage

When water is supplied intermittently, users must use some kind of storage to have water available at all times. Water storage can exacerbate the problem of intermittent supplies as users drain the system to store as much water as possible, rather than using enough for their immediate needs. Water storage can also lead to water contamination through unsafe storage practices (Lee and Schwab 2005). Water can become contaminated in storage by keeping the storage vessel uncovered, dipping unwashed hands into the storage containers, or due to contamination within the vessels themselves.

1.3. Research Objectives

The goal of this research is to illustrate the connection between the intermittent piped water supply in Tamale, Ghana and poor water quality in households connected to the piped water system. In order to accomplish this goal, three objectives have been defined, as follows:

1. Water quality must be tracked through the entire distribution system, from the treatment plant, into the distribution system and in households, showing where the quality of the water diminishes and to what degree.

2. Household water storage will be investigated as a possible cause for diminished water quality.

3. The system will be modeled using a hydraulic model to show possible routes of contamination and quantitatively show the need for household storage.

1.4. Structure of Thesis

In Section 2, background information is presented on the research location and drinking water regulations. Section 3 presents a review of relevant literature related to intermittent water supplies and household water quality. Sections 4 and 5 present research methodology and results respectively and Section 6 contains the discussion of the research results. In Sections 7.1 and 7.2, recommendations are given for improving water quality, through improvements to the piped water supply system and household storage practices.

2. Background

2.1. Tamale

Tamale is the third largest city in Ghana, and the largest in the Northern Region (Ghana Statistical Services 2012). As of the 2010 census, the population of the total metropolitan area was 371,351 people (Ghana Statistical Services 2012). According to the 2010 census, 73 % of the population lives in "urban" areas, classified as any defined and named area with more than 5,000 inhabitants. According to the 2008 Ghana Demographic and Health Survey (GDHS) 28% of households in Northern Ghana use water from unimproved sources (Ghana Statistical Service (GSS), Ghana Health Service (GHS), ICF Macro 2009). A map of Ghana is shown in the figure below:

Figure 2–1: Map of Ghana showing Tamale (source: http://www-pub.iaea.org/)

2.2. Piped Network in Tamale

Municipal water in Tamale is treated and supplied by the Tamale Region office of the Ghana Water Company Ltd. (GWCL), a state-owned limited liability company overseen by the Ministry of Water Resources Works and Housing.[3] GWCL treats water from the White Volta River using conventional treatment at the Dalun-Nawuni treatment plant (Okioga 2007). In 2008 Biwater/Farrer Consulting completed a project to expand the capacity of the Dalun-Nawuni

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[3] GWCL website: http://www.gwcl.com.gh/pgs/hmp.php

treatment plant from 19 to 44 million liters per day (MLD) (5 to 11.6 million gallons per day (MGD)).[4]

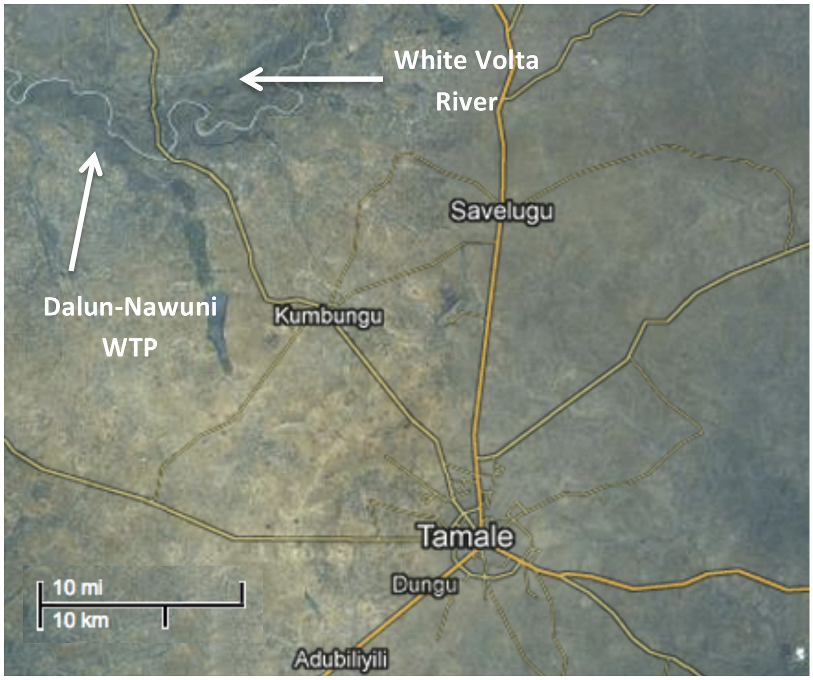

Figure 2–2: Location of Dalun-Nawuni WTP (from Google Maps)

The project also included an expansion of the piped water network and the establishment of District Metered Areas (DMAs) to help regulate water in the system and reduce non-revenue water. A DMA is an area of the distribution system with valves closed to have only one common inlet and outlet connecting to the larger distribution system. In the Tamale system, each DMA is intended to have a bulk meter at the common inlet/outlet along with a data logger to record flows and pressures in and out of the DMA. This kind of discretization of the system is to allow GWCL to track water losses in the system and identify specific areas (DMAs) where non-revenue water is leaving the system. The following figures show a photograph of a bulk water meter located at the common inlet/outlet of one DMA (left) and a photograph of a data logger used to record flow and pressure data. The data logger is attached to the bulk meter via cables and can be programmed by plugging in to a laptop computer.

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[4] Biwater website: http://www.biwater.com/Articles/273257/Biwater/BW_home/water_treatment/water_treatment_projects/Tamale_Ghana.aspx

Figure 2–3: Bulk Meter for A1 (SSNIT)

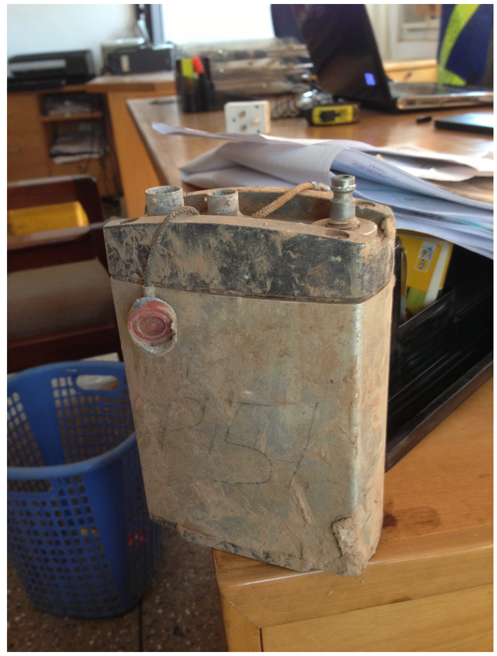

Figure 2–4: Flow and Pressure Data Logger

Despite the improvements to the system, after conversations with GWCL employees and observations in the field, it is clear that there is still room for improvement in the Tamale piped network. Through these conversations and observations, the following model of interrelated challenges has been developed, as shown in the figure below. This model can be generalized and adapted to describe other water systems in developing countries, but is based on the issues encountered in Tamale in particular.

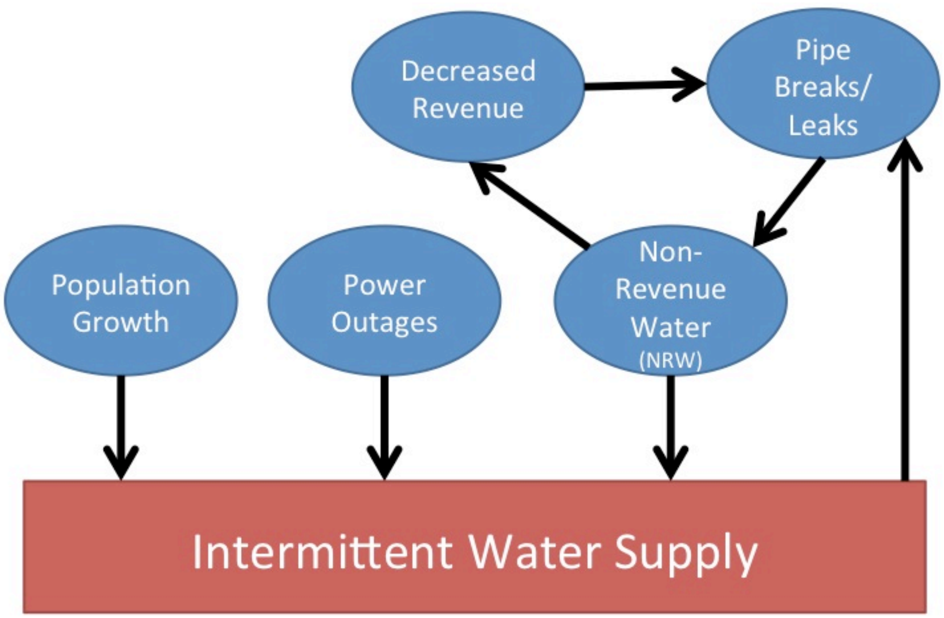

Figure 2–5: Factors Leading to Intermittent Water Supply in Distribution Systems

Factors affecting intermittent water supply in distribution systems:

1. **Population Growth:** Tamale is growing rapidly and more users are moving into the system, straining the already limited water supply, leading to more intermittency.

2. **Power Outages:** electricity service in Tamale has been quite intermittent in recent months, leading to outages of the pumps that supply the distribution system, leading to an **Intermittent Water Supply.**

3. **Decreased Revenue:** underpayment for water and low levels of government funding lead to low revenue for the system. This lack of funding makes it difficult to fund capital improvement project and to maintain the system, leading to more **Pipe Breaks/Leaks.**

4. **Pipe Breaks/Leaks:** as pipelines and valves age, more maintenance is required and performance deteriorates leading to more leakages and pipe breaks. This leads to more water losses, increasing **Non-Revenue Water. Intermittent Water Supply** also puts more strain on the pipe network; leading to more breaks and leaks.

5. **Non-Revenue Water (NRW):** NRW = water produced minus water sold. Includes real losses (leaks, spills) and apparent losses (water used without being paid for). Apparent losses can be caused by illegal water connections as well as unmetered connections or broken meters. NRW is a serious problem in Tamale, with levels sometimes exceeding 50% of water supplied from the Dalun-Nawuni WTP (according to conversations with GWCL staff). NRW decreases the already scarce supply of water for the system population, contributing to an **Intermittent Water Supply**. NRW also contributes to the problem of **Decreased Revenue** for GWCL, as water is being produced but not paid for.

2.3. Drinking Water Regulations and Guidelines

This research focuses on distribution system water quality and storage. Water quality in any distribution system is a function of the water quality at the treatment plant outflow as well as conditions in the distribution system. In the following section, drinking water regulations in the United States, international drinking water guidelines, and Ghana drinking water standards are summarized, with special attention paid to standards for distribution system water quality.

2.3.1. US Standards

In the United States, federal and state drinking water regulations all have at their core, the Safe Drinking Water Act (SDWA). The SDWA, passed by Congress in 1974 and amended in 1986 and 1996, sets basic requirements for public drinking water systems and authorizes the United States Environmental Protection Agency (US EPA) to enforce the act. Within the body of drinking water regulations, there are rules and guidelines pertaining to water supply, treatment, storage and distribution. The regulations related to distribution can be separated into three different approaches, which combined, ensure the distribution of safe drinking water.

- Contaminant monitoring

Under this approach, water systems are required to monitor treated water in the distribution system for a variety of contaminants and chemicals. Each type of major contaminant is regulated under its own rule. This research will focus primarily on the microbial water quality as measured by indicator bacteria and disinfectant residual and therefore the following rules are most relevant:

  - The Total Coliform Rule[5] requires routine sampling for presence of coliform bacteria at a representative set of sample sites in the distribution system. The number of sites is determined by the population served and the locations are determined by the water utility, subject to approval by the primacy agency (typically the state government). If coliform bacteria is detected, repeat samples are collected. If any of these samples test positive for coliform bacteria, the water must then be tested for *E. coli*. Systems are in compliance with the rule based on the number (or percentage) of samples collected in a month that are positive for total coliforms, and whether there were any samples positive for *E. coli.* Large systems are required to show that 95% of all samples have non-detectable levels of total coliform.

  - The Surface Water Treatment Rule[6] regulates systems treating and distributing surface water. In the distribution system, this rule requires routine sampling for disinfectant residual (typically chlorine), collected at the same time and locations as the coliform samples. Systems are in compliance if disinfectant residual is undetectable in less than 5% of samples in a month for less than 2 consecutive months. This rule also requires a minimum chlorine residual of 0.2 mg/L to be maintained.

  - The Stage 2 Disinfectant/Disinfection Byproduct Rule[7] specifies a maximum disinfection residual level of 4.0 mg/L chlorine in the distribution system.

- Operator certification

This approach regulates the personnel authorized to operate a distribution system. Operators can achieve different certification levels through training, experience, and written exams. Different types of distribution systems require different levels of operator certification. This program is administered by the individual states and requirements in each state vary.

- Sanitary surveys/risk reduction

This approach seeks to protect the finished piped water from outside contamination through surveys and risk reduction. Systems are required to conduct periodic sanitary surveys to identify potential hazards and take appropriate remedial actions. The frequency and specific requirements for these surveys vary by state, water source, and population served. Risk reduction is also

[5] Rule website: http://water.epa.gov/lawsregs/rulesregs/sdwa/tcr/regulation.cfm
[6] Rule website: http://water.epa.gov/lawsregs/rulesregs/sdwa/swtr/
[7] Rule website: http://water.epa.gov/lawsregs/rulesregs/sdwa/stage2/index.cfm

achieved through waterworks standards regulating maintenance and new construction practices. These standards set guidelines for minimum pressures in pipes and proper main repair techniques (maintaining pressure, disinfection requirements). There are no federal standards for water main installation and repair, but many U.S. utilities use the American Water Works Association (AWWA) standards as a reference[8]. California requires systems to adhere to waterworks standards, most of which are adopted directly from AWWA. California also requires systems to maintain pressures of at least 20 psi (1.38 bar) to prevent contamination.

2.3.2. Ghana Standards

Drinking water standards for Ghana are less readily available online compared to US regulations and WHO guidelines. One resource that was obtained was the Ghana Standard No. 175-1:2008, which outlines water quality standards for both municipal drinking water and packaged (bottled) drinking water (Ghana Standards Board (GSB) 2008). This standard specifies a "maximum" free chlorine residual of 0.2 mg/L. Based on the context of the standard this is believed to be a typographical error, and it is assumed that a *minimum* free chlorine residual of 0.2 mg/L is required. This assumption is supported by the presence of a footnote in the standards that states that "When protection against viral infection is required, it should be 0.5 mg/L, min". The standards specify that no *E. coli* should be detected in a 100 mL sample (Ghana Standards Board (GSB) 2008). There are no requirements listed for sanitary surveys or operator certifications but during conversations with GWCL staff it was apparent that staff was aware of the WHO framework for drinking water quality and were seeking to replicate that model eventually (outlined below). The Ghana standard lists the *2004 WHO Guidelines for Drinking-Water Quality* as a bibliographic reference, along with *Standard Methods for the Examination of Water and Wastewater* (1998 edition).

2.3.3. International Guidelines

The World Health Organization (WHO) has published guidelines for drinking water quality. These are guidelines, not enforceable standards or regulations. However they are widely cited and used by many countries around the world as guidance in setting their own national drinking water standards. The WHO guidelines present a "framework for safe drinking-water" whose purpose is to provide a "preventive, risk-based approach to managing water quality" (World Health Organization 2011). This framework has at it's core three main components: (1) health-based targets, (2) Water Safety Plans (WSP), and (3) Surveillance. A visual representation of the WHO guidelines conceptual framework is shown in the following figure.

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[8] http://www.awwa.org/store/standards.aspx?Category=STAND

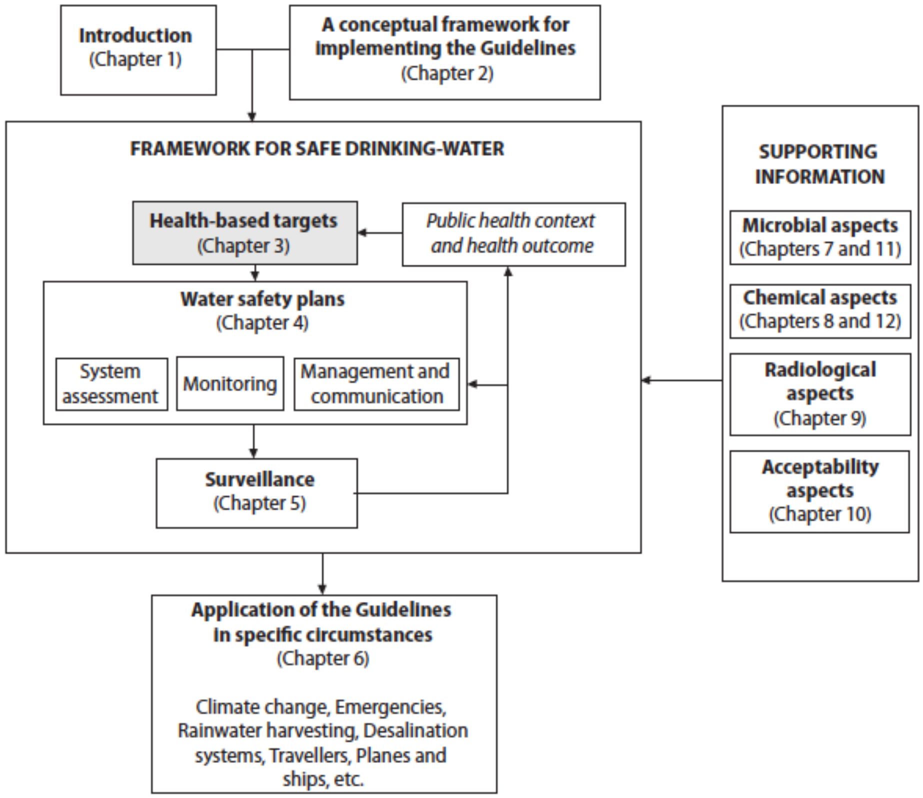

Figure 2–6: WHO Guidelines Conceptual Framework (from Ch. 3 of WHO Guidelines for Drinking-Water Quality, 2011)

- Health-based targets

The health-based targets can be divided into four types: (1) health outcome targets, (2) water quality targets, (3) performance targets, and (4) specified technology targets. These four types of targets are summarized in the following table, (taken from Chapter 3 of the 2011 WHO Guidelines).

Table 2-1: WHO Guidelines Description of Health-based Targets (Table 3.2 in 2011 WHO Guidelines)

Type of target	Nature of target	Typical applications	Notes
Health outcome	Defined tolerable burden of disease	High-level policy target set at national level, used to inform derivation of performance, water quality and specified technology targets	These Guidelines define a tolerable burden of disease of 10^{-6} DALY per person per year
	No adverse effect or negligible risk	Chemical or radiological hazards	Derived from international chemical or radionuclide risk assessments
Water quality	Guideline values	Chemical hazards	Based on individual chemical risk assessments
		Microbial water quality targets are not normally applied	*Escherichia coli* is used as an indicator of faecal contamination and to verify water quality
		Radiological water quality targets are not normally applied	Radiological screening levels are applied
Performance	Specified removal of hazards	Microbial hazards (expressed as log reductions)	Specific targets set by water supplier based on quantitative microbial risk assessment and health outcome targets or generic targets set at national level
		Chemical hazards (expressed as percentage removal)	Specific targets set by water supplier based on chemical guideline values or generic targets set at national level
Specified technology	Defined technologies	Control of microbial and chemical hazards	Set at national level; based on assessments of source water quality, frequently underpinned by established or validated performance of the specified technology (e.g. requirement of filtration for surface water)

Evaluation of health outcome targets requires data on public health, such as incidence of diarrheal disease and infant mortality, which is outside the scope of this research. Specified technology and performance targets focus primarily on treatment technology and performance rather than distribution system technology and performance and are therefore also not the focus of this research. Adherence to water quality targets can be easily evaluated during a short time in the field, as has been the case with this author's three week field research period. Among the WHO's four health-based targets, water quality is therefore the target of interest of this research.

The two water quality guidelines of interest for this research are those regulating microbial contamination (as measured by indicator bacteria) and disinfectant residual. For microbial contamination, the WHO Guidelines state that *E. coli* "Must not be detectable in any 100 mL sample" (World Health Organization 2011). Although this guideline is ideal for ensuring safe water, the WHO has classified levels of *E. coli* detected into four risk categories, summarized by the following table:

Table 2-2: WHO Sanitary Risk Categories (Table 5.2 in 2011 WHO Guidelines)

		Sanitary inspection risk score (susceptibility of supply to contamination from human and animal faeces)			
		0–2	3–5	6–8	9–10
E. coli classification (as decimal concentration/100)	< 1				
	1–10				
	11–100				
	> 100				

Low risk: no action required	Intermediate risk: low action priority	High risk: higher action priority	Very high risk: urgent action required

For disinfection using chlorine (as the Tamale system does), the WHO guideline calls for a maximum of 5 mg/L of chlorine in the system and a minimum of 0.2 mg/L at the "point of delivery" (World Health Organization 2011).

- Water Safety Plans

The Water Safety Plan framework (center left of Figure 2-6) can be divided into three main components: (1) System Assessment, (2) Monitoring, and (3) Management and Communication. Due to the short time frame of this study, long-term monitoring is not feasible and changes to the management and communication of the Tamale system is outside the scope of the research. Therefore, the System Assessment component is most relevant to the research described here. The System Assessment is broken up into six modules, which are intended to be completed sequentially. The modules are as follows:

1. *Describe the water supply system*

   This module calls for a detailed, accurate description of the water supply system from source to tap, including maps, system operation descriptions, and household surveys. For a piped system, the system description can include flow diagrams and maps as well as current water quality data and household survey results.

2. *Identify hazards and hazardous events and assess the risks*

   This module calls for examining the entire supply chain of water (from source to tap) and identifying and describing all possible hazards and hazardous events that could compromise water supply and water quality. Once the hazards and hazardous events are identified, the risks to the water supply associated with these hazards is determined and described. For a piped distribution system typical hazards considered are water pressure fluctuations, intermittent supply, main breaks, and illegal connections.

3. *Determine and validate control measures, reassess and prioritize the risks*

   This module involves identifying and validating control measures that can be used to reduce the risks identified in Module 2. For a piped distribution system, control measures can include up-to-date maps, pipe protection, pressure monitoring, and site security measures.

4. *Develop, implement and maintain an improvement/upgrade plan*
In this module, the control measures identified in Module 3 are incorporated into short, medium and long-term plans and implemented by the utility.

5. *Define monitoring of the control measures*
In this module, a monitoring plan is defined and established to demonstrate if the control measures are effective at mitigating risks to the water supply. Monitoring parameters for a piped distribution system can include disinfectant residual, pH, and turbidity.

6. *Verify the effectiveness of the WSP*
In this final module of the system assessment, the system is routinely inspected and audited to verify that the WSP is effectively reducing risk and harm to the system.

- Surveillance
This component consists of monitoring the treatment plant and distribution system to ensure that the WSP is being followed, and that health-based targets are being met. This process also provides feedback to refine and improve the WSP and targets. For distribution systems, surveillance should include an assessment as to the quality, quantity, accessibility, affordability, and continuity of the water supply. In addition, the WHO Guidelines state that surveillance must extend beyond the operations of the water supplier to include "assurance of good hygiene in the collection and storage of household water" (World Health Organization 2011).

In this research, the WHO guidelines will be used as the primary reference to evaluate the Tamale distribution system, as these guidelines are more comprehensive and detailed than the available Ghana standards, and are more applicable to Ghana than the US standards.

3. Literature Review

3.1. Intermittent Water Supplies and Water Quality

While there is a wealth of literature available on the operation and management of distribution systems, most of this literature is targeted towards systems in developed countries where the continuity of water supply is taken as a given. Some literature exists referring to intermittent water supply in the event of a catastrophic system failure (such as after an earthquake) but this type of emergency response work is primarily geared towards rehabilitating a system and restoring continuous water supply, and therefore will not be used for this analysis. When intermittent water supply is mentioned in research of systems in developing countries, it is often referenced as a problem to be solved, with little attention paid to the daily operation of such a system.

However, there are a select group of researchers dedicated to the topic of intermittent water supply design and operation, and the quality of water in such systems. In an article by Lee and Schwab (2005) the authors give a broad overview of deficiencies in distribution systems in developing countries, including intermittent water supply. **The authors described the causes and effects of intermittent water supply and summarize relevant research associated with these types of systems**. The authors categorize intermittent pressure as a separate deficiency from intermittent water supply but acknowledge that the two concepts are interrelated. When the supply of water is intermittent, the pressure must by definition be intermittent as well, as a lack of water causes a lack of pressure. However, intermittent pressure can occur in a continuous water supply. For the purpose of this research, intermittent pressure is treated as a characteristic of intermittent water supply and not as a separate issue.

Other authors have studied the affect of intermittent supply systems on water quality in more detail but have generally paid less attention to the hydraulics of the system. Coelho et. al conducted a study (2003) that most closely approximates this analysis, combining hydraulic modeling of intermittent systems with household water storage sampling. Coelho's study compares three intermittent systems in Lebanon, Jordan, and Palestine, to two continuous systems in the UK and Portugal. The authors were able to model water quality changes in the Jordan system using a customized hydraulic model to simulate the unique characteristics of an intermittent system. While the results of the model calibration yielded results within the margin of error of laboratory testing, the model did not adequately account for changes in water quality that were observed. Thus, more work was recommended on refining a modeling system that can be used for intermittent systems. Based on the water quality sampling conducted, the authors concluded that "the influence of household storage tanks is paramount in water quality deterioration" in intermittent system (Coelho and al. 2003). **The deterioration observed was significant enough for the authors to declare that any improvement in quality gained through treatment was effectively cancelled out by the reduction in quality that occurred in household storage** (Coelho and al. 2003)**.**

A study by Andey and Kelkar (2007) systematically examined the performance of four urban water distribution systems in India under both intermittent and continuous water supply scenarios. For both scenarios data on pressure, flow, per capita water consumption, waste levels and water quality were collected and analyzed. For this analysis, the water quality findings are the most relevant. The authors found compelling results, with 90-100% of samples testing negative for coliform bacteria under continuous water supply, while 24-73% of samples tested negative under intermittent water supply. Based on these results, **the authors concluded that**

intermittent water supply systems present a greater public health risk than continuous water supply systems (Andey and Kelkar 2007)**.**

In Beirut, Lebanon, a study was conducted by Tokajian and Hashwa (2003) to assess the effects of intermittent water supply on bacteriological water quality. Over two years, samples were collected at a series of tanks in the distribution system and analyzed for total coliforms, fecal coliforms, and heterotrophic plate counts (HPC). The sites were distributed along a straight line in the system with water flowing in series from one site to the next. **A significant increase in HPC bacteria was observed between the first and last sites in the series, indicating some deterioration in quality in the system itself.** In addition, water quality was seen to decline in the tanks themselves after being stored for a week (Tokajian and Hashwa 2003).

3.2. Household Water Storage

Many resources on household water treatment and storage (HWTS) were found that address household water quality issues. Most of these articles focus on treatment and storage in the home as linked factors in improving household water quality. However, a few focus more specifically on household water storage independent of treatment. Since this study does not include research on household treatment methods, articles that focused on storage were given priority in the literature review.

Jensen and others conducted a 5-week intervention study in a small village in Pakistan to study the relative significance of domestic contamination in household storage (Jensen, et al. 2002). Study participants were given new water storage containers: approximately half received wide-necked pitchers while the other half received narrow-necked pitchers. **The results of the study showed that contamination of drinking water at the household level is only significant when the source water is relatively clean (i.e. less than 100 cfu/100 mL of *E. coli*).** When source water is highly contaminated, the authors found that household interventions (such as distributing narrow-necked storage containers) has little to no impact on final water quality.

In an article by Mintz, Reiff, and Tauxe (1995), the authors describe a two-pronged strategy to reducing waterborne disease: disinfecting water after collection, and safe storage of water after disinfection. The authors explicitly point out that water quality problems can occur even with municipal piped water, "because of inadequately maintained pipes, low pressure, intermittent delivery, lack of chlorination, and clandestine connections" (Mintz, Reiff and Tauxe 1995). The authors also cite evidence that improper household storage can cause recontamination of previously safe piped water. The purpose of this article was to promote a new (at the time) strategy for preventing waterborne disease, and therefore describe intervention studies and design criteria for safer water storage vessels in some detail. **The authors focus on a solution to the problem of contaminated drinking water in households and spend relatively little time discussing the causes.**

In 2004, Wright, Gundry, and Conroy conducted a large-scale meta-analysis of studies measuring bacterial contamination of drinking water at the source and in household storage (Wright, Gundry and Conroy 2005). The analysis includes 57 field-based studies conducted in developing countries using coliform bacteria as the indicator bacteria, where water was transported from a source and stored in the home. The studies include those where the water source was unprotected as well as some using piped municipal water. While the studies using unprotected source water are not as relevant to the current study, all other inclusion criteria for the meta-analysis matched the current study parameters, as the study took place in a developing country (Ghana), tested water in household storage, and used coliform bacteria as the indicator bacteria. (See Section 4: Research Methodology, for more details on the setup of this research). The meta-analysis by Wright, Gundry, and Conroy concludes that **roughly half of the studies analyzed show a significant deterioration in water quality after collection and storage, and none show a significant improvement in microbiological water quality after collection and storage.** The analysis indicated that the deterioration in water quality is proportionally greater in cases where the source water was uncontaminated. The authors point out that these are often improved sources, such as wells and municipal connections.

Most of the studies that were found in the literature examine the recontamination of water by humans, through poor hygiene practices. However, one study conducted in Jordan examined microbial regrowth in storage tanks that occurred without human contact (Evison and Sunna 2001). In this study, four storage tanks were disinfected and installed on the roof of a laboratory building in Amman, Jordan. The tanks were filled and emptied every four or seven days in a pattern consistent with average household use. Over the course of 10 months, the study finds increased microbiological contamination (measured by heterotrophic plate counts) in the stored water even in the absence of human contact with the water. Although coliform bacteria is not detected, the increase in heterotrophic plate counts (HPC) indicates that microbial activity increases with longer storage time and higher temperatures. **The authors therefore conclude that "non-continuous flow may harm water quality" and recommend that action be taken to minimize the adverse affects of storing water**. The fact that water quality deteriorated in the absence of human contact with the water supports the notion that intermittent water supply is a fundamental contributing factor in decreased water quality; even if hygiene practices are improved, there is still the possibility of contamination.

3.3. Modeling of Intermittent Water Supply Systems

Batish (2004) clearly explains the differences between the operation of a conventional, continuous water supply system and an intermittent water supply system and outlines a new approach to designing and modeling a distribution system based on these differences. The author uses Indian systems as examples and some of the characteristics of intermittent systems he cites are particular to India. For example the author noted that the cost of water in India is highly subsidized and that cost is not a major concern for most Indian consumers, which is not the case in other developing countries, including Ghana (Batish 2004). **Despite these particularities, the author generally gives a blueprint for intermittent system design that can be applied anywhere, along with detailed instructions for modeling such a system.** Water quality is not addressed in the article, but Batish fills a gap in the literature with regard to hydraulic operation of intermittent systems.

Sashikumar, Mohankumar and Sridharan discuss in detail the theoretical differences between modeling a continuous water supply network and an intermittent network (Sashikumar, Mohankumar and Sridharan 2003). While their work is primarily based in Bangalore, the issues described are applicable to any intermittent water supply network. **In particular, the authors focus on the issues of variable Hazen-Williams C values and large peak load factors as the key differences between modeling continuous and intermittent networks.** The authors find that the Hazen-Williams C value (pipe roughness factor) varies considerably over short periods of time (on the order of one day) in an intermittent system as the pipes fill and air pockets are pushed out. The authors also find that peak load factors are much larger than those usually reported in the literature (for continuous systems) since users are consuming enough water at one time to last several days (Sashikumar, Mohankumar and Sridharan 2003). This article does not describe any specific modeling software but rather outlines theoretical modeling issues that are common to any software.

Ingeguld and others discuss their experience using EPANET to model intermittent water supply systems in India and Bangladesh(Ingeguld, et al. 2006). **In order to use EPANET, which is designed for continuous water supply systems, the authors had to adjust the program to take into account the pressure-dependent nature of demand and the presence of household storage tanks.** In a continuous system, demand drives the flow of the system, with users taking water whenever needed. In an intermittent system the availability of water and pressure drive demand, with users taking as much water as possible when the water is available. The authors modeled this in EPANET by programming in rules that governed demand based on pressure, rather than the more typical model of programming based on fixed demands (Ingeguld, et al. 2006). Household storage tanks were assigned based on GIS data, sometimes assigning one large tank to represent a group of household size storage tanks.

Cabrera-Bejar and Tzatchkov have proposed a solution combining EPANET and the Storm Water Management Model (SWMM), two freely available computer models (Cabrera-Bejar and Tzatchkov 2009). EPANET is designed to model demand-driven distribution system models, while SWMM is intended to be used to model rainfall-runoff entering storm drains. **Cabrera-Bejar and Tzatchkov propose using SWMM to model the initial charging of empty distribution system pipes that would occur when water is diverted to an empty portion of the network. Once the section of the system is fully charged, EPANET can be used to model the system flows.**

Kala Vairavamoorthy (together with others) has written many articles and book chapters on the topic of modeling intermittent water supply systems and is widely cited by the other authors mentioned here. He has written extensively on the theory of modeling intermittent distribution systems as well as developing several modeling tools (Vairavamoorthy, et al. 2001) Most recently, he and others have developed a model called Integrated Risk Assessment of Water Distribution Systems (IRA-WDS) that can be used to predict contamination in intermittent water supply systems (Vairavamoorthy, Yan and Gorantiwar 2007). **This model consists of three sub-models: contaminant ingress, pipe condition assessment, and risk assessment models, which are combined to form the IRA-WDS model.** This model has been applied to a water distribution network in South India and has generated reasonable results.

4. Research Methodology

The general research approach seeks to undertake a rapid assessment of the system, thereby maximizing the value of the three weeks spent in the field in Tamale, Ghana during January 2013. To that end, three approaches to the research were carried out concurrently:

1) Utilize existing GWCL data whenever possible, especially concerning treatment and system water quality.

2) Gather qualitative information from individual households regarding storage practices and water continuity.

3) Gather household water quality data to support the GWCL data and provide a more detailed view of the drinking water quality issues in the urban and peri-urban areas served by the GWCL.

In addition, upon return from Ghana in February, a fourth approach was attempted:

4) Use GWCL GIS data to create a hydraulic model of the distribution system and model possible causes of intermittency in the system.

4.1. GWCL Data and Reports

Data from GWCL was provided to the researcher in digital format (Microsoft Excel spreadsheets and Microsoft Word Documents). Monthly water quality monitoring reports in Excel format were provided for January through November 2012. Since reports are prepared in the month following data collection, the December 2012 report was not available as of January 2013 when field research was being conducted. All data is compiled in a single spreadsheet in Appendix C.

Water quality data consists of monitoring results from the Dalun-Nawuni WTP as well as data from the distribution system. Water samples at both locations were tested for *E. coli,* chlorine residual, color, pH, and turbidity. All water quality results were obtained according to Ghana national drinking water standards (Ghana Standards Board (GSB) 2008), which specify the laboratory procedures to be used for each water quality test.

Figure 4–1: GWCL Regional Laboratory

In addition to numerical data, more qualitative data was provided in the form of project reports, operations manuals, and other documents used for training new staff members. Biwater/Farrer Consulting staff authored many of these documents during the distribution system expansion project and some were still in draft form or were incomplete. These documents were used to gather background information and support personal communications with GWCL but will not be referenced explicitly in this research.

4.1.1. Data Limitations

According to the water quality manager, Mr. Yakubu Adam, samples are collected in different public locations every month to try to represent a broad cross-section of the system. Therefore the data is a good spatial representation of conditions in the distribution system. However, since the sample locations vary from month to month it is not possible to track water quality changes at a specific location over time. The distribution system water quality monitoring data was provided in the form of monthly summary reports. This meant that each of the sample results was presented as a single number (pH, temperature, chlorine residual, etc.) with no supporting information such as location, date and time of sample, name of sample collector, laboratory method. More specific data such as location, date and time of each sample is contained in hand-written laboratory notebooks stored at the water quality laboratory. Due to time constraints, those original records were not observed or copied while in Ghana but this would be a valuable exercise in the future.

4.2. User Surveys

4.2.1. Location of Surveys

In order to better understand the effects of an intermittent supply on individual water users, a house-to-house survey was conducted in four different neighborhoods within the city of Tamale, as shown on the map below:

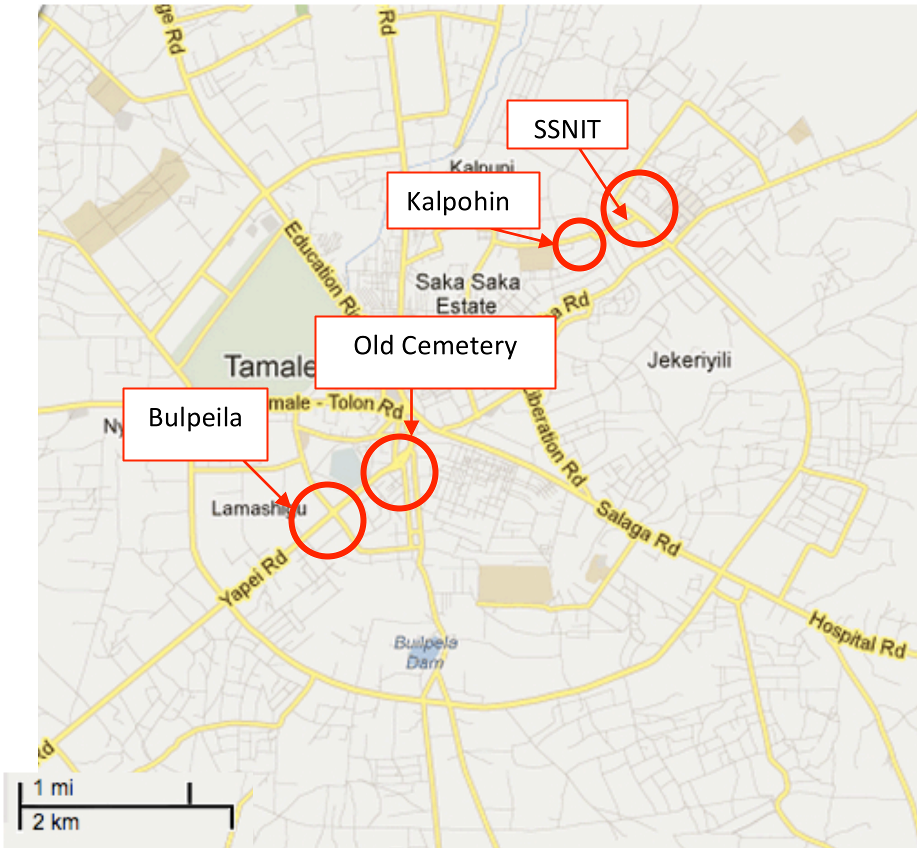

Figure 4–2: Map of Tamale showing approximate survey areas (From Google Maps)

A total of 40 surveys were conducted across the four neighborhoods, described below:

- <u>Kalpohin Estates [15 surveys]:</u> This neighborhood is located off the Dagomba Road, a busy paved road running east out of the downtown Tamale area. This neighborhood consists mostly of single-family detached homes with gated yards. This neighborhood was chosen for its convenience as the researcher was living in this neighborhood during the field study period.

Figure 4–3: Aerial view of Kalpohin Estates (from Bing maps)

- SSNIT Flats [9 surveys]: The Social Security and National Insurance Trust (SSNIT) flats are located about three miles east of Tamale center and consist of a large complex of apartment blocks. Each block is 4 stories high and contains 8 individual apartments. The neighborhood was chosen for its convenient location near Kalpohin Estates, and due to the fact that it is near the edge of the service area and therefore likely to have a very intermittent water supply.

Figure 4–4: SSNIT Flats Neighborhood

- Old Cemetery [8 surveys]: This neighborhood is located in the downtown center of Tamale. The housing varies from single-family detached homes to multifamily walled compounds. These compounds consist of several buildings around a central courtyard and typically house large families. This neighborhood was chosen due to the fact that it completely contains a District Metered Area (DMA) that was reported by GWCL staff to have better than average continuity and water pressure.

Figure 4–5: Old Cemetery Neighborhood

- Bulpeila [8 surveys]: This neighborhood is also located near the center of Tamale and contains mostly multifamily walled compounds, similar to Old Cemetery but with more open space between buildings. Similarly to Old Cemetery this neighborhood was chosen due to the fact that it completely contains a DMA that was reported by GWCL staff to have better than average continuity and water pressure.

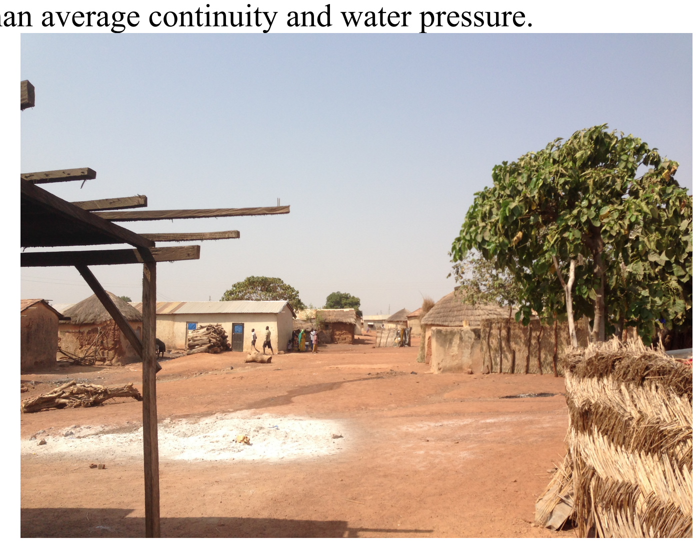

Figure 4–6: Bulpeila Neighborhood

In each neighborhood, surveys were conducted simply by walking through the neighborhood, without any prior planning, and were therefore limited to availability of respondents at the time of the surveys. Surveys were conducted over the course of seven days between January 4 and January 21, 2013. Initial surveys in the Kalpohin Estates neighborhood were conducted with the assistance of a translator from the NGO Pure Home Water, which hosted the MIT team, who translated questions when needed from English to Dagbani and Twi, the two most common Ghanaian languages spoken locally in this area. The researcher conducted subsequent surveys without a translator in English. There is a possibility that this could skew the results towards more educated users who speak English. However, in practice there were only two occasions where a respondent did not speak English and a suitable translator from the neighborhood (a son, sister, neighbor, etc.) could not immediately be found.

4.2.2. Survey Methodology

An initial survey was designed before beginning field research, based on core questions suggested by the WHO and UNICEF in their "Core Questions on Drinking-Water and Sanitation for Household Surveys" (WHO and UNICEF)as well as Howard's suggested sanitary survey questions (Howard 2002). The figure below shows the original survey questions, parts I and II.

Part I: Core Questions Adapted from "Core Questions on Drinking-Water and Sanitation for Household Surveys, by WHO/UNICEF	**Part II: Sanitary Survey For Piped Water Supply** Adapted from "Water Quality Surveillance: A Practical Guide" by Guy Howard
1. What is the main source of drinking water for members of your household? 2. What is the main source of water used by your household for other purposes such as cooking and hand washing? 3. How long does it take to go there, get water, and come back? 4. Who usually goes to this source to fetch the water for your household? Is this person under 15 years of age? What gender? 5. Do you treat your water in any way to make it safer to drink? 6. What do you usually do to the water to make it safer to drink?	1. Do any sample taps/household taps/standpipes leak? 2. Does water collect around sample site? 3. Is area uphill eroded at sample site? 4.Are pipes exposed close to sample site? 5. Is human excreta on ground within 10m of standpipe? 6. Sewer or latrine within 30m of sample site? 7. Has there been discontinuity within last 7 days at sample site? 8. Are there signs of leaks in sampling area? 9. Do users report pipe breaks in last week? 10. Is the supply main exposed in sampling area? For service reservoir only: 11. Is the service reservoir cracked or leaking? 12. Are the air vents or inspection cover insanitary?

Figure 4–7: Original Household Survey Questions – Pre-Test

These surveys were chosen for the broadness of the questions and their wide applicability. For example, Part I of the survey could be applied to a household that uses any source of water ranging from a piped connection inside the house to a dug well many miles from home. This section of the survey addresses water quality concerns (i.e. questions 5, 6) as well as social questions such as who is responsible for water collection (i.e. question 4). Part II of the survey, “Sanitary Survey for Piped Water Supply”, is intended to establish the risk of contamination of a piped water supply through examining sanitary conditions around the tap or standpipe.

The pre-test survey was carried out for the first two days of surveys in Kalpohin Estates. As a result of information gained from the pre-test surveys, the survey was revised after the initial pre-test was completed. These changes included adding follow-up questions as well as eliminating questions to focus the survey. Because of the intermittency of the piped network it was observed that in all of the pre-test interviews users stored large quantities of water in order to have an adequate supply. Upon making this observation the scope of the research was re-conceptualized to focus on household storage and the quality of water in these storage vessels (Objective 2 in Section 1.3). Accordingly, several questions were added to the survey to gather information specifically related to household storage, as follows.

Part III: Storage Survey Questions

1. Do you store water in your household?
2. What kind of storage vessel do you use?
3. Do you ever clean your storage vessels?
4. How often do you clean your storage vessels?
5. What do you use to clean your storage vessels?

Figure 4–8: Storage Survey Questions

Many pre-test respondents provided information about past discontinuities in the piped water system in addition to answering the original question, Part II-7 “Have there been discontinuities at the samples site in the last seven days?” In order to make use of this information, the question was expanded to solicit information on discontinuities in general, not just in the past week. Due to the large number of respondents reporting water outages for multiple weeks, an additional question was added: “If the water is off for a long period of time, does your household have a secondary source of water that is used?” This question provides insight into how intermittent supply can cause users to resort to secondary, often less sanitary sources of water.

All interviews were conducted in an urban environment where users had household connections to the piped water supply or else nearby public connections. Therefore, questions 3 and 4 from Part I were eliminated. In conducting the initial round of surveys, respondents made clear that they believed the first question of Part II - “Do any household taps leak?” to be unnecessary, as any leaks are fixed immediately. To paraphrase one respondent’s answer: “No, of course we don’t have any leaks, that would be wasting money”. In the interest of streamlining the survey, that question was dropped from the revised survey. All surveys were conducted in users homes, so only the conditions of household taps were observed. Questions 2-6, 8, and 10 of Part II relate primarily to conditions at public standpipes and were therefore dropped from the survey in the interest of streamlining the survey. Similarly, no service reservoirs were observed so questions 11 and 12 from Part II were also eliminated. In addition to adding and subtracting questions, the survey team adjusted the language on many questions to be better understood by the respondents. For example, Part II, Question 7 asks “Has there been discontinuity within the last 7 days at this sampling site?” The word “discontinuity” was not known to many of the initial respondents in the context of water supply, so the wording was changed to “How often is the water flowing from the piped supply?” The final revised survey is shown in Figure 4-9. Each survey took approximately 15-20 minutes including collecting samples and conducting chlorine residual testing.

Revised Household Survey

1. What is the main source of drinking water for members of your household?
2. Where is the piped connection located?
3. What is the main source of water used by your household for other purposes such as cooking and cleaning?
4. Do you treat your water in any way to make it safer to drink?
5. What do you usually do to the water to make it safer to drink?
6. Do you store water in your household, and in what type of vessel?
7. Do you clean your storage vessels? If yes, how often, and how are they cleaned?
8. How often is the water flowing from the piped supply?
9. If the water is off for long periods of time, is there another source of water used by members of your household? [if yes, repeat questions 1-5 for this source]
10. Have you observed any pipe breaks in your area in the last 2 weeks?

Figure 4–9: Revised Household Survey

4.2.3. Possible Sources of Bias

Surveys were conducted on weekdays between 9:00 hrs and 18:00 hrs, with the majority of surveys conducted between 9:00 hrs and 11:00 hrs. See figure below for the frequency distribution of survey times. This range of survey times was chosen partially for the convenience and safety of the researcher and also to allow time for laboratory analysis of samples in the late afternoon and evening. This choice of survey time meant that most users who work outside the home were not surveyed, possibly skewing the results away from educated professionals. In Kalpohin Estates, most residents were away from home during the survey times, and most results from that neighborhood were taken from surveys with household staff. This presents a further source of bias, as those residents who work and do not employ household staff were excluded from the study because neither they nor members of their staff were at home during the survey times. In SSNIT flats neighborhood more residents appeared to be at home during the daytime working hours, with the majority of respondents being women. In the Bulpeila and Old Cemetery neighborhoods many residents appeared to work from their homes, with men as well as women available for surveys.

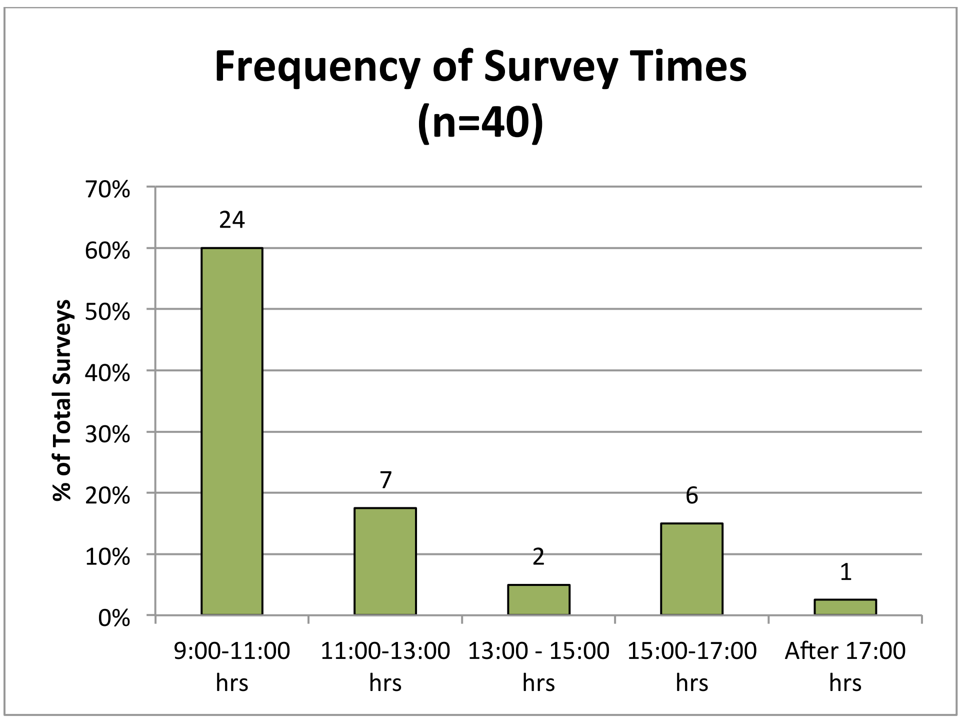

Figure 4–10: Survey Time Frequency

In addition to bias in selection of respondents, bias may have been introduced by the questions in the survey. The survey was revised based on the pre-test surveys, all of which took place in the Kalpohin Estates neighborhood. In the Kalpohin Estates neighborhood, most water was stored in large, sealed, polyethylene tanks ("poly tanks") so it was not necessary to add more detailed questions about the type of storage used. In other neighborhoods the storage methods were more diverse, and it would have been helpful to develop a list of storage characteristics to check rather than record each unique combination of storage vessels. Although biases are present, the survey results are intended to show qualitative information about user behavior and perceptions of the system and are not to be taken as a statistically representative sample of the population.

4.3. Household Water Quality Testing

All samples were collected from household storage using 10 mL vials for total chlorine tests and sterile Nasco Whirl-Pak® sampling bags for bacteriological tests. However, the method of collection varied according to the configuration of the household's water supply. In houses where storage tanks were directly connected to taps, samples were collected from the taps directly into the 10 mL bottle or sampling bags. The samples were collected without touching the sample container to the tap, but the taps were not sterilized before sample collection in order to reflect actual household water quality conditions. The sample was collected during the initial flow of water from the tap rather than after a flushing period in order to avoid waste of water belonging to the respondents. In households where water was stored in a drum or jar, the respondents were asked to fill a drinking cup with water that was then poured into the sample container. Having the respondent collect the sample was meant to ensure that samples are representative of water actually used by the respondent, including any possible contamination from the users.

Figure 4–11: Samples in sample bags (Photo Credit: Kristine Cheng)

4.3.1. Chlorine Residual

Chlorine is a powerful oxidant, and is an effective disinfectant due to its ability to oxidize enzymes of microbial cells, reducing the ability of the cells to survive (Reynolds and Richards 1996). The effectiveness of chlorine as a disinfectant is dependent on many factors, such as chlorine dosage, turbidity, pH, temperature, and contact time. After chlorine is applied to water, a portion of the dosage is used to oxidize the organic materials and bacteria present. This is the chlorine demand. The remaining portion of the dosed chlorine is the chlorine residual. This remaining chlorine can continue to oxidize contaminants that are introduced after the dosing is complete (Reynolds and Richards 1996).

Chlorine residual was selected as a key water quality parameter for this study for several reasons. First, the presence of a chlorine residual can indicate the absence of disease-causing bacteria and the ability of the water to resist becoming bacteriologically contaminated. Second, since GWCL treats the drinking water at the Dalun-Nawuni WTP with chlorine at known, consistent, dosages, measuring the residual can provide a simple comparison of water quality in the distribution system versus the treatment plant. There are no additional chlorine addition points within the distribution system. Third, chlorine residual testing can be done very quickly and effectively in the field, using a minimum of equipment.

At every household surveyed, samples were collected and tested immediately for residual chlorine using a colorimeter (Hach Pocket Colorimeter II®). The instrument uses DPD powder pillows and was used in accordance with the standard method recommended by the manufacturer, which is equivalent to the US EPA method and the Standard Method 4500-CL G (American Public Health Association; American Water Works Association; Water Environment Federation 2012). See Appendix A for the complete method by Hach.

Figure 4–12: Hach Pocket Colorimeter II (source: www.camlab.co.uk)

4.3.2. Coliform Bacteria and *E. coli*

Bacteriological sampling was conducted at 32 of the 40 households surveyed. If a sample showed total chlorine residual of 0.20 mg/L or higher, no bacteriological sample was collected as it was assumed that no coliform bacteria would be present under those conditions. This assumption was based on US Federal Drinking Water regulations, which require a disinfectant residual of 0.2 mg/L or higher at the entry point to the distribution system for all systems treating surface water (U.S. Environmental Protection Agency 1989). As the Tamale system uses treated surface water, 0.2 mg/L residual chlorine was considered to be an appropriate, conservative indicator for the absence of coliforms. Using this metric, 3 samples were considered coliform-free without the need for further biological testing. In addition, 5 samples were not tested for coliform bacteria from the first two days of surveys in the Kalpohin Estates neighborhood (the “pre-test surveys”), to conserve testing materials while the sampling plan was refined.

Samples were collected during the interviews (in the daytime) and stored temporarily in an insulated portable cooler until all interviews were completed for the day. The samples were then stored in a refrigerator in the laboratory for a maximum of 4 hours before being tested on the same day as collection. Samples were tested for total coliforms and *Escherichia coli* (*E. coli*) bacteria using the IDEXX Quanti-Tray/2000® Most Probable Number (MPN) method. Total coliforms are not the ideal indicator bacteria, especially for tropical climates, as they can occur naturally in the absence of fecal contamination (Droste 1997). However they are the most convenient, standardized test for indicator bacteria currently available and it was outside the scope of this study to explore alternative testing methods. The IDEXX Quanti-Tray/2000®

method gives results of Most Probable Number (MPN) per 100 mL sample. This unit is for practical purposes equivalent to CFU/100 mL but indicates the specific method used to generate the value. See Appendix B for a summary of MPN vs. CFU provided by IDEXX. The WHO Guidelines include a list of acceptable methods for *E. coli* detection including ISO Standard 9308-3:1998 which is an MPN method (World Health Organization 2011). See Appendix C for the complete procedure.

4.4. Hydraulic Model

Water distribution networks are large complex systems and some kind of computer modeling is usually necessary to track flows and water quality within the network. Most hydraulic modeling software in use today was developed with continuous systems in mind and operate under the assumption that pipes are always pressurized and that users take water as needed simply by opening their taps. Movement of water in the network occurs due to customer demands on the system and therefore these types of models are often referred to as a "demand-driven models" (Cabrera-Bejar and Tzatchkov 2009). In contrast, in intermittent water distribution networks, pipes are not always pressurized and water is not continuously supplied to users. Movement of water in the network is governed by the supply of water available and therefore models of these systems are referred to as "supply-driven models" (Cabrera-Bejar and Tzatchkov 2009) or "pressure dependent outflow" (PDO) models (Vairavamoorthy, et al. 2001).

While some researchers such as Vairavamoorthy have developed custom models to deal with intermittent systems, these models are not widely available and would likely be impractical for use at GWCL due to their lack of structured technical support. GWCL uses a SynerGEE model made by the GL Group[9] that has been calibrated to the Tamale system. However, the staff member trained to use the model no longer works in the Tamale office (in Accra instead) and could not be reached to discuss the model. Due to these limitations, modeling using EPANET was determined to be the most feasible option, given the fact that it is freely available software and several others have made use of it to model intermittent water supplies (Ingeguld, et al. 2006) (Cabrera-Bejar and Tzatchkov 2009).

[9] http://www.gl-group.com/en/water/SynerGEEWater.php

5. Results

5.1. GWCL Water Quality Data

GWCL provided monthly water quality reports for January – November 2012. These reports summarized water quality data from the water treatment plant as well as from the distribution system. All data is included in Appendix D.

5.1.1. GWCL Chlorine Results

The figure below shows average plant chlorine residuals plotted along with average distribution system sample results. There were between 81 and 93 samples taken each month at the Dalun-Nawuni Treatment Plant outflow and 60 samples taken each month in the distribution system.

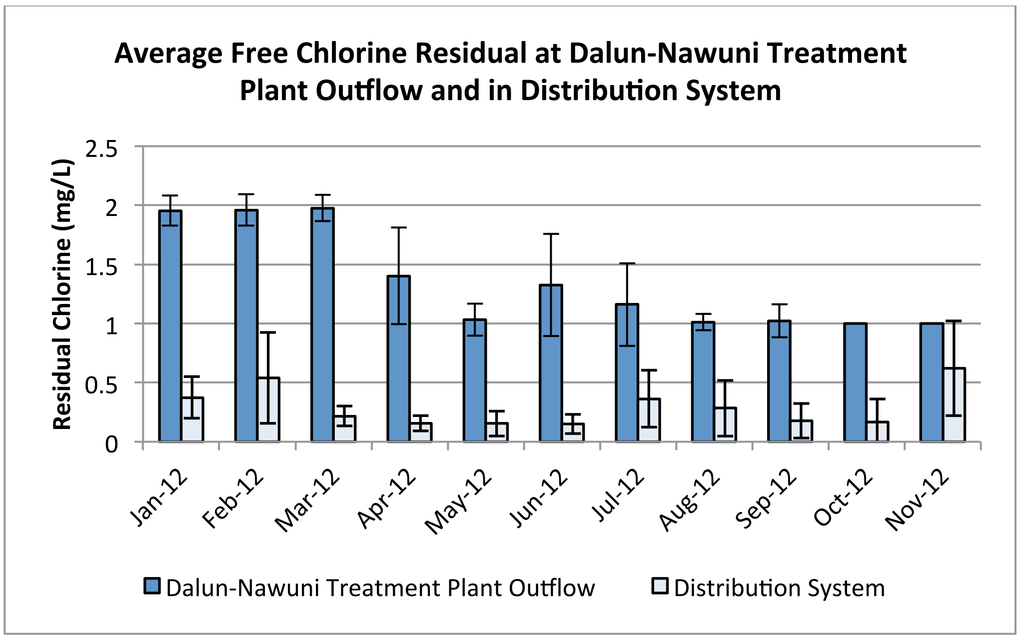

Figure 5–1: Reduction in free chlorine residual from treatment plant to distribution system

As shown in the figure, during most months the average chlorine residual reduced dramatically from the treatment plant outflow to the distribution system. The mechanisms for this decay will be discussed further in Section 6.

5.1.2. GWCL Bacteriological Results

All samples, at the treatment plant and the distribution system, tested negative for *E. coli*. Samples were not tested for total coliforms by GWCL.

5.2. Household Survey Results

The following summarizes the findings of the household surveys. For a complete listing of all household survey responses, see Appendix E. In addition, a map of survey locations for Kalpohin Estates is included in Appendix F.

5.2.1. Types and Locations of Water Sources

All users surveyed had access to a piped water connection, although this was not the primary drinking water source for all households. Of the users surveyed, 30% did not use piped water as their primary drinking source, preferring vended water packaged in sealed plastic bags ("sachet" water) instead.

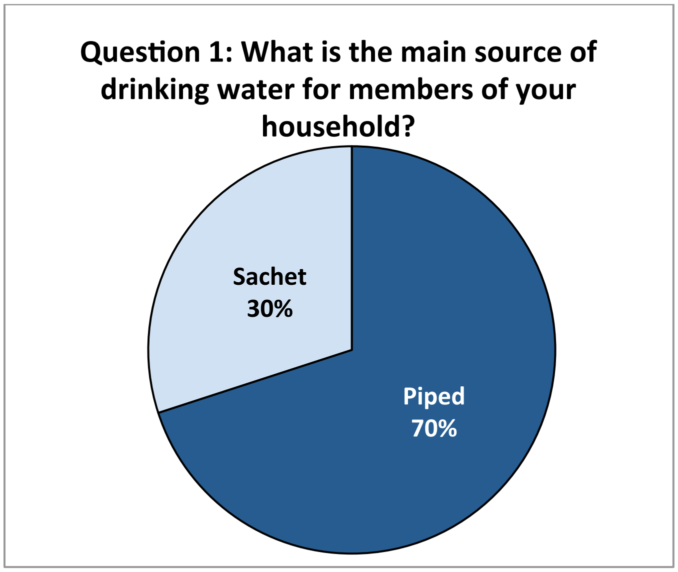

Figure 5–2: Survey Question 1: What is the main source of drinking water for members of your household?

The majority of users (77%) surveyed responded having a connection within their household. Of these household connections, some were located inside the home, in the form of kitchen and bathroom taps while others had taps located outdoors in the courtyard of their houses. The remaining 23% of users did not have their own piped water connection, but made use of a public standpipe or a neighbor's connection. For the purposes of this research, use of a neighbor's connection is grouped under the heading "Public Tap". These categories correspond to the first two types of connections listed under "improved" on the WHO/UNICEF Joint Monitoring Program "Drinking Water Ladder"(Figure 1-1). The first category, "Piped water into dwelling, yard, or plot" is abbreviated to "Household Connection" and the second category, "Public tap or standpipe" is abbreviated to "Public Tap".

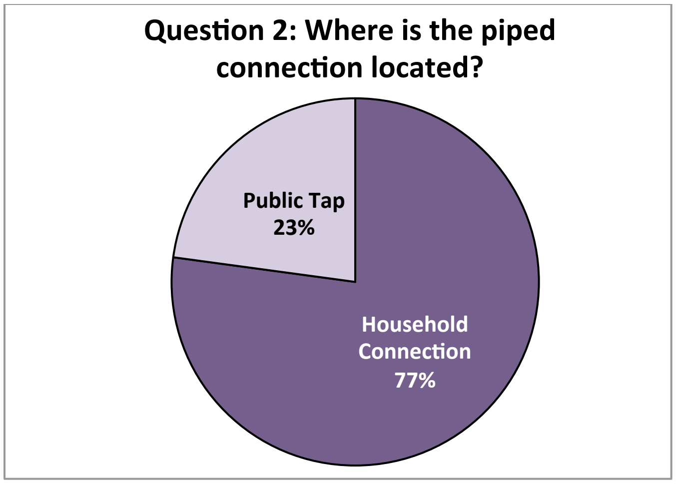

Figure 5–3: Question 2: Where is the piped connection located?

Although all users surveyed had access to a piped water connection, 30% of the users did not use piped water as their primary drinking source, preferring vended water packaged in sealed plastic bags ("sachet" water) instead. All users reported using piped water for non-drinking purposes, such as cooking and cleaning. One user however, in the Bulpeila neighborhood reported making use of a shallow well for household cooking and cleaning when piped water was not available.

Many users also reported secondary sources of water that they resorted to when the piped water was unavailable for a long period of time, and stored water was depleted. Of the forty surveys conducted, 16 users reported using a secondary source of drinking water in these types of situations. Of the 16 users, half reported using tanker truck water that is normally piped water provided by GWCL directly or sold by GWCL to tanker truck operators. Three users each reported using sachet water or borehole water. One user reported using a neighbor's water supply as the neighbor lived on a lower floor and often had better water pressure. Finally, one user reported that they used a local dugout (surface water) source of water.

5.2.2. Household Water Treatment

Of the 70% of users who drank piped water, only 25% treated the water prior to drinking. When asked if they treated their drinking water, several respondents expressed surprise that piped water would require further treatment. When asked if she boiled her piped drinking water, one respondent in Kalpohin Estates responded that she did not, because she "assumed that they [GWCL] have already boiled it."

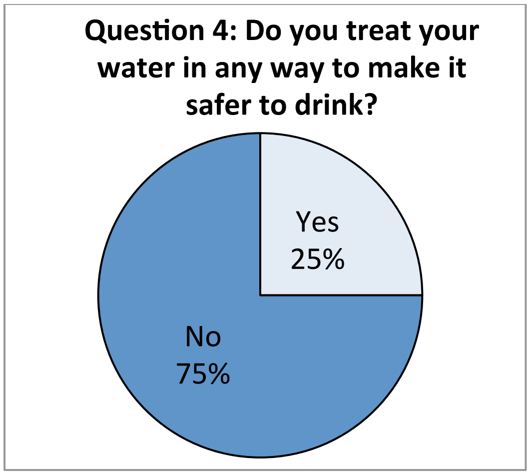

Figure 5–4: Question 4: Do you treat your water in any way to make it safer to drink?

Of the eight respondents who did report to treat their piped water, half made use of a household filter, three boiled their water and one reported boiling and then filtering water before drinking. Of the five respondents using filters, three used porous ceramic filters made by Pure Home Water (PHW), a local NGO, while the two others used other commercially available point-of-use filters. Of the three that reported boiling their water, one respondent reported that she did not boil her own water before drinking, but always did so for the young children in her household. Of the eight respondents that reported treating their drinking water, three lived in Kalpohin Estates, four in SSNIT Flats, and only one in the Old Cemetery neighborhood.

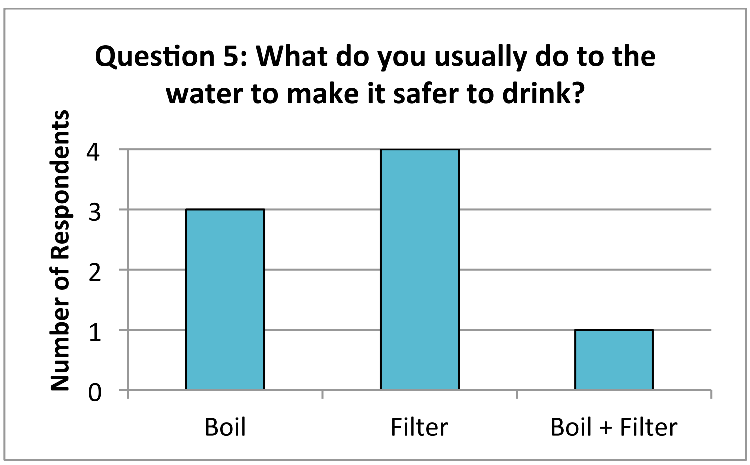

Figure 5–5: Question 5: What do you usually do to the water to make it safer to drink?

5.2.3. Household Storage Practices

All users surveyed reported storing water in their households. Storage vessel size, quantity and type varied greatly between households and between neighborhoods. Of the storage vessels observed in the surveys, seven basic types were identified, classified mainly by material. Many users had a combination of storage vessels. In these cases the different types of vessels were observed, but the exact number of each type was not recorded. A description and photograph of each type is shown in the following table. All photographs were taken by the researcher in the field.

Table 5-1: Types of Storage Vessels

Vessel Type	Material	Approximate Capacity	Photograph
Poly Tank	Polyethylene or similar plastic	Varies 200-25,000 L (44-5,556 gal)	
Metal Drum	Steel	200 L (55 gal)	
Clay Pots	Ceramic	Varies 75-200 L observed (20 – 50 gal)	
Plastic Drum	Plastic	200 L (55 gal)	

Steel Tank	Steel	8000 L (2100 gal)	
Jerry Can	Plastic	5-10 L (1-3 gal)	
Cement Tank	Cement	Varies 1000-2000 L observed (300-500 gal)	

The following figure shows the distribution of different types of water storage observed during the surveys. For households with multiple types of storage, each type was counted once, without weighting for number of vessels or quantity of water stored. The steel tanks were only present at SSNIT flats, and some respondents reported that the tanks came with the apartment. All other types of storage were present in each neighborhood to varying degrees. Poly tanks were predominant in Kalpohin Estates, and clay vessels were only found in Old Cemetery and Bulpeila.

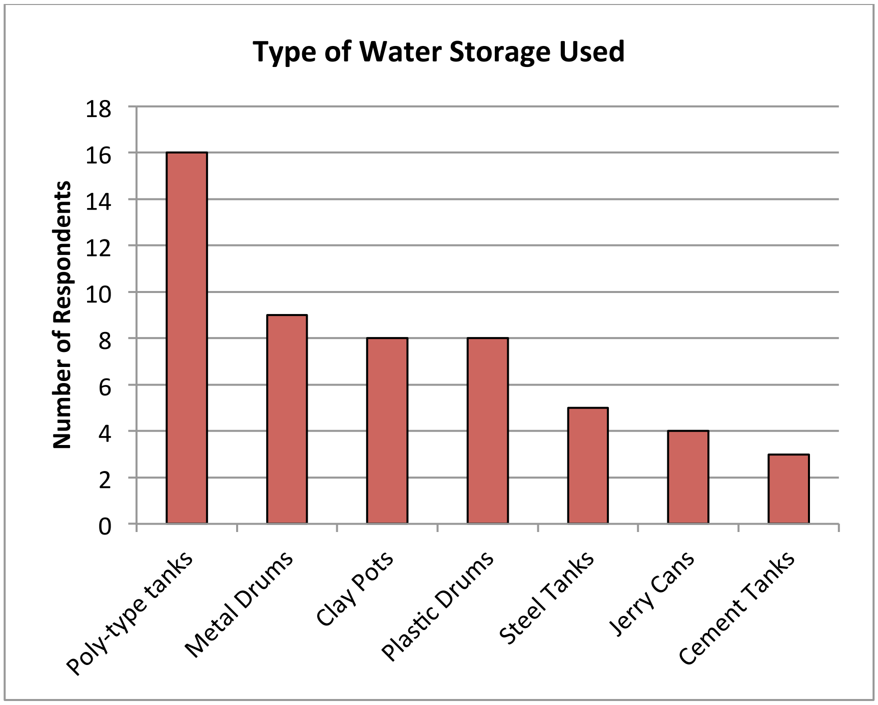

Figure 5–6: Types of Storage Vessels Observed

Every respondent reported cleaning their water storage vessel, but with widely varying degrees of frequency. The most common frequency was "whenever it is empty" which, depending on the size of the vessel could vary from once every couple days, to once in several years. When asked for more details of exactly how often the storage vessel was cleaned, most respondents could not say with precision.

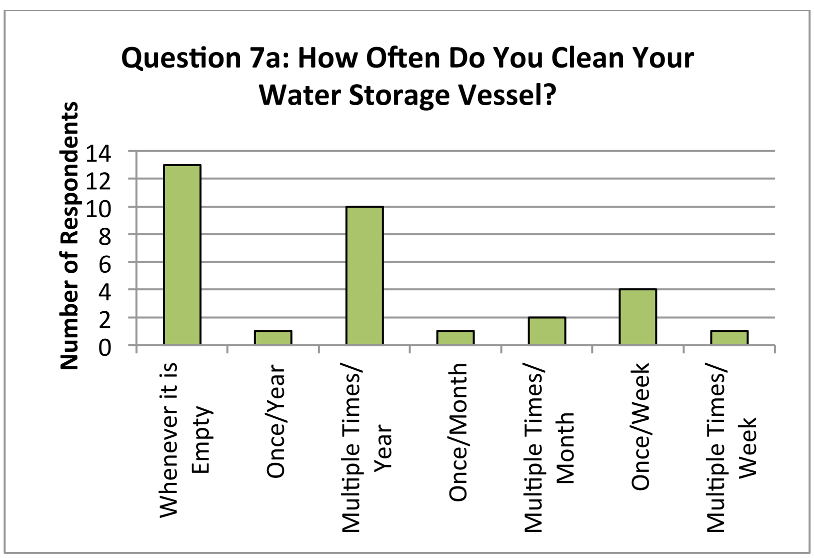

Figure 5–7: Question 7a: How often do you clean your water storage vessel?

Almost two thirds of respondents reported using identical cleaning techniques, namely Omo® powdered laundry soap and a sponge or brush. This type of soap is widely popular in Tamale, and is used for laundry, dish washing, and other household cleaning. While it is feasible to clean jerry cans and open vessels, the poly tanks are much more difficult to clean with soap given the narrow opening in the top. It is possible that respondents with poly tanks misunderstood the question and were referring to their methods of cleaning the exterior of the tank, rather than the interior.

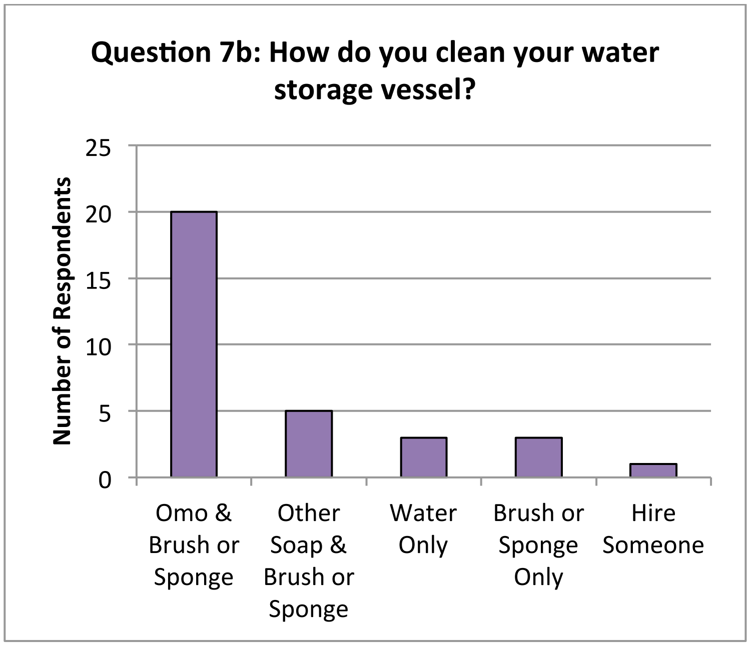

Figure 5–8: Question 7b: How do you clean your water storage vessel?

5.2.4. Continuity of Supply

When asked about the continuity of the water supply, respondents gave widely varying and at times vague answers. On several occasions the response to the question "How often is the water flowing?" would be "all the time", but when asked more specific follow-up questions, it was discovered that "all the time" meant several days a week, or once a day. Also, there were many instances where respondents living close to one another would give extremely different answers, calling into question the accuracy of the data. With the assumption therefore, that the responses are not necessarily reflective of actual network conditions, these responses can be taken as an indicator of user perception of the continuity of the water supply.

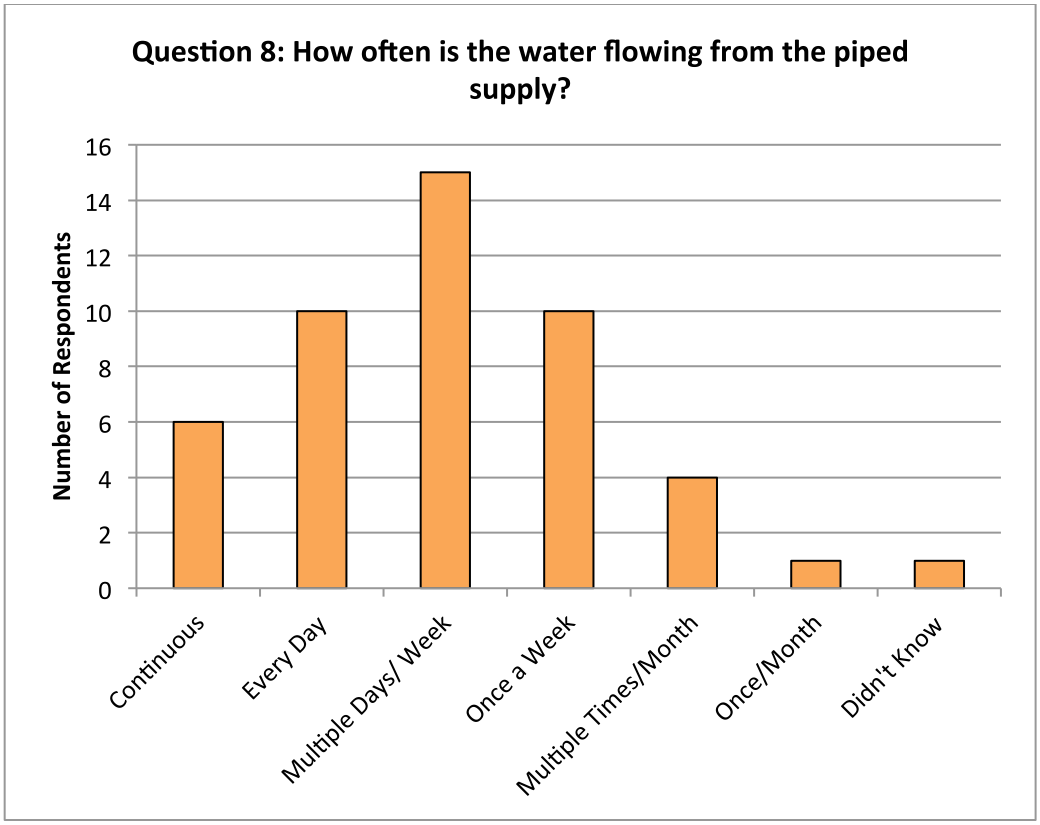

Figure 5–9: Question 8: How often is the water flowing from the piped supply?

5.3. Household Water Quality

In most of the households surveyed, a water sample was collected and tested for chlorine residual, total coliform and *E. coli*. Although there are numerous other physical and chemical indicators of water quality, disinfectant residual and presence of coliform bacteria are two of the primary indicators of water safety.

5.3.1. Household Chlorine Results

A total of 40 samples from household storage were tested for total chlorine residual.

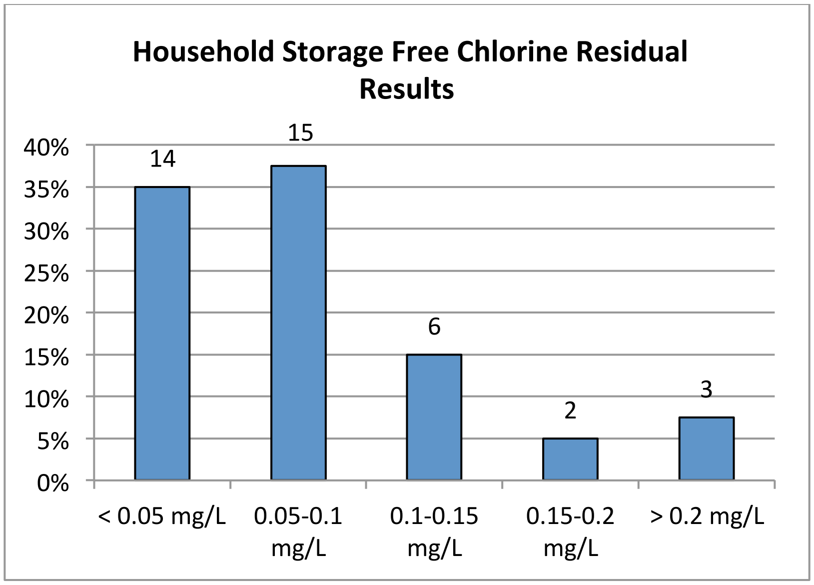

Figure 5–10: Household Storage Free Chlorine Residual Results

The vast majority of the samples (92%) tested below the threshold of 0.2 mg/L set by the US EPA in the Surface Water Treatment Rule as a minimum to avoid bacteriological contamination. Of the 40 households surveyed, 33 samples were tested for total coliform and *E. coli*. In their Guidelines for Drinking-Water Quality, 4th Edition, the WHO classifies bacteriological contamination as falling into one of four categories of risk, dependent on the level of *E. coli* found in samples(World Health Organization 92).

- <1 CFU/100 mL *E. coli*: "Low Risk", no further action required.
- 1-10 CFU/100 mL *E. coli*: "Intermediate Risk", low action priority
- 11-100 CFU/100 mL *E. coli*: "High Risk", higher action priority
- >100 CFU/100 mL *E. coli*: "Very High Risk", urgent action required

The 33 samples are grouped according to these categories in the following figure.

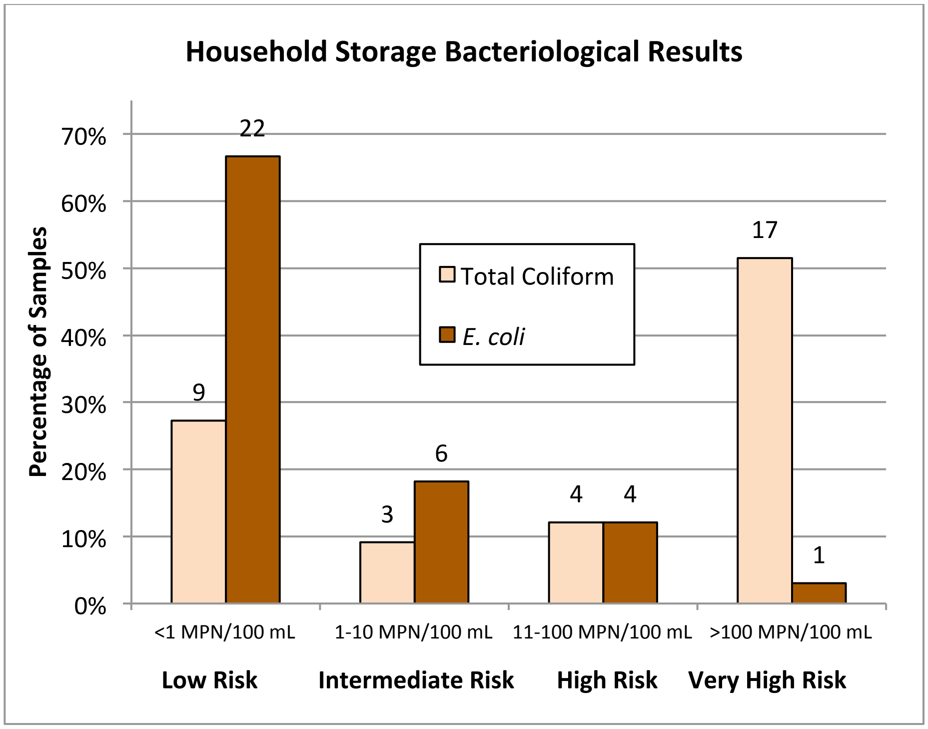

Figure 5–11: Household Storage Bacteriological Results

The majority of samples fall into the "low risk" category, with levels of *E. coli* less than 1 CFU/100 mL. 30% of the samples fell under the "intermediate risk" and "high risk" categories combined for *E. coli* results. Only one sample fell into the "very high" risk category. This sample came from a shallow dug well in the Bulpeila neighborhood that was used primarily for cooking and cleaning purposes. However, it is possible that this water is used by other households in the area for drinking water and therefore is a cause of concern.

Figure 5–12: Shallow Well in Bulpeila Neighborhood

As expected, total coliform results were much higher overall than *E. coli*. 73% of samples had detectable levels of total coliform (greater than 1 MPN/100 mL) and more than half the samples showed levels of total coliform bacteria higher than 100 MPN/100 mL. While not as high an indicator of risk as *E. coli*, the WHO recognizes that total coliform can be used as an indicator of treatment performance and distribution system cleanliness and integrity (World

Health Organization 2011). Furthermore, in the United States, the EPA requires that 95% of monthly distribution system samples test negative for total coliforms (U.S. Environmental Protection Agency 1989) a standard clearly not achieved by these household samples.

5.4. System Performance Modeling

Geographic information systems (GIS) shapefiles were obtained from GWCL for the piped network of three DMAs: A1 (SSNIT), C5 (Bulpeila), and C7 (Old Cemetery). Figure 5-13 below shows the GIS data provided by GWCL in map form. The map shows the layout of the piped water network, drawn with varying line widths according to pipe diameter (in mm). The map also shows valve locations, meter locations, and DMA boundaries.

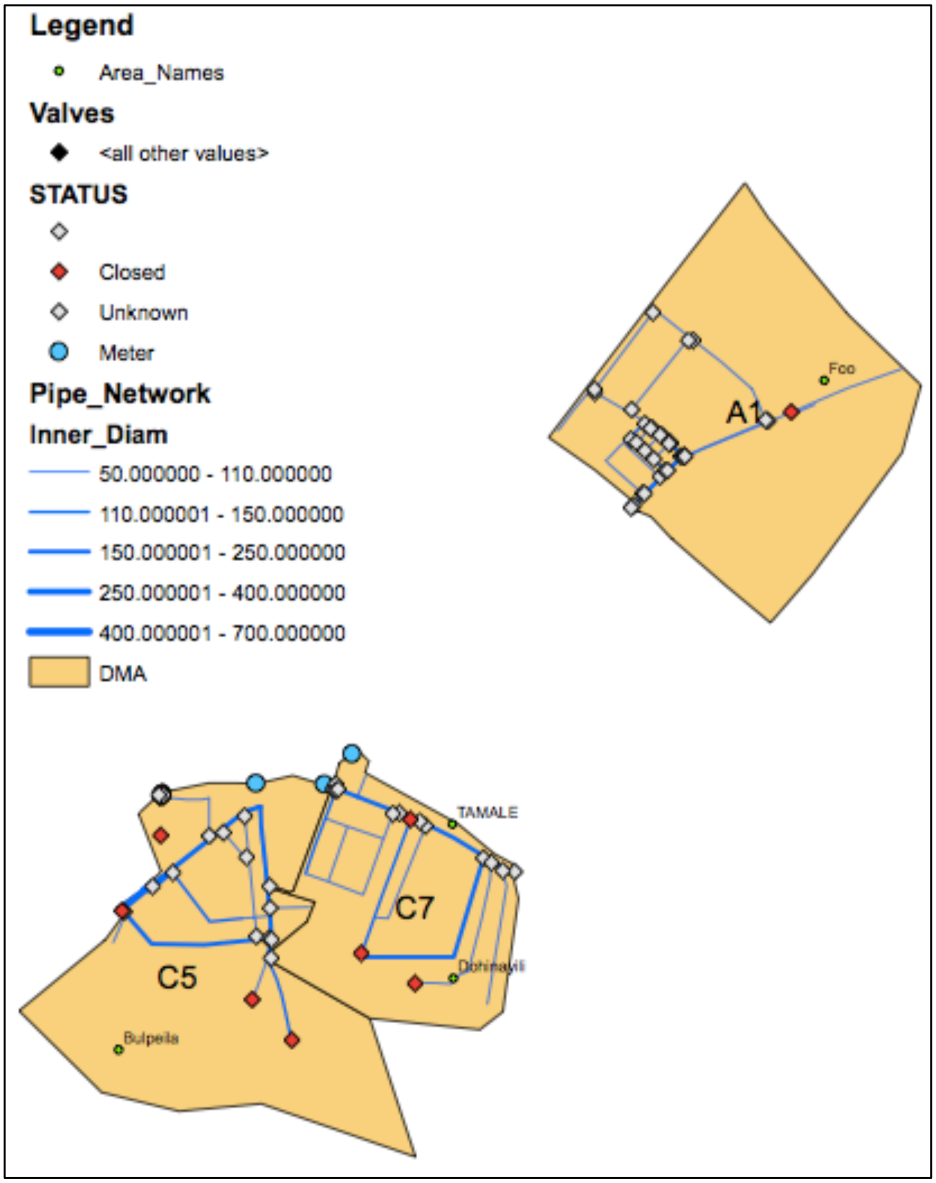

Figure 5–13: GIS Data Provided by GWCL

The GIS data was converted to .inp format suitable for use in EPANET and imported into EPANET. It was not possible to obtain flow and pressure data for these DMAs by the deadline for this thesis. Without flow and pressure data, the model could not be calibrated to actual system conditions. Without a calibrated model, it was not possible to simulate different scenarios that could cause intermittency in the system (power outages, water losses, etc.) as shown schematically in Figure 2-5. Figure 5-14 below shows a screenshot of the EPANET model in its present (unfinished) form. The model consists only of the piped network with no valves, tanks, meters, or other appurtenances included.

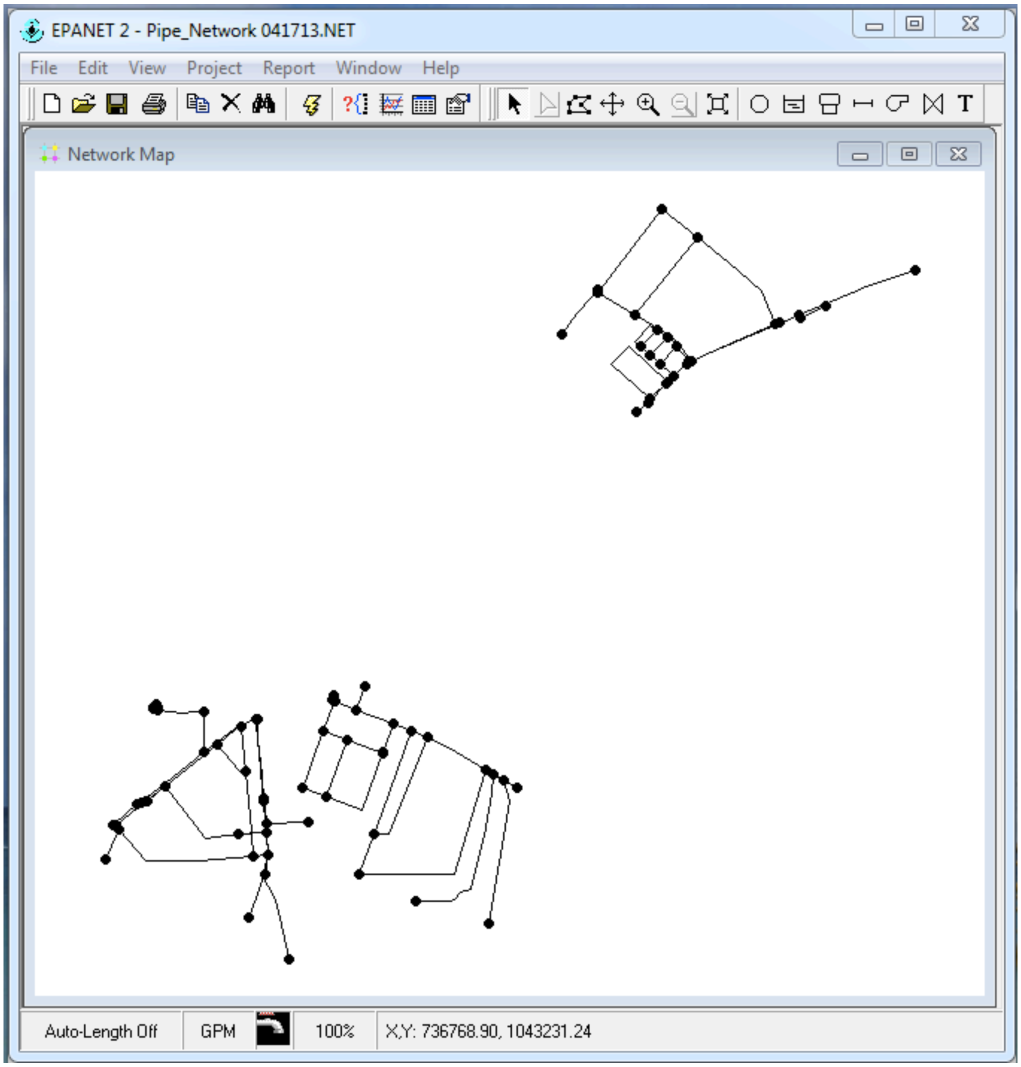

Figure 5–14: Screenshot of EPANET Model

Despite being unable to calibrate the model, the flow and pressure data that has been made available to the author can provide a more quantitative assessment of the intermittency in the system. The following figures show flow and pressure at the entrance to the SSNIT flats neighborhood (DMA #A1) and the Old Cemetery neighborhood (DMA #C7). This data was recorded at 15 minute intervals over the course of 4 days in early May. Pressure is shown in pounds per square inch (psi) and flow is shown in gallons per minute (gpm).

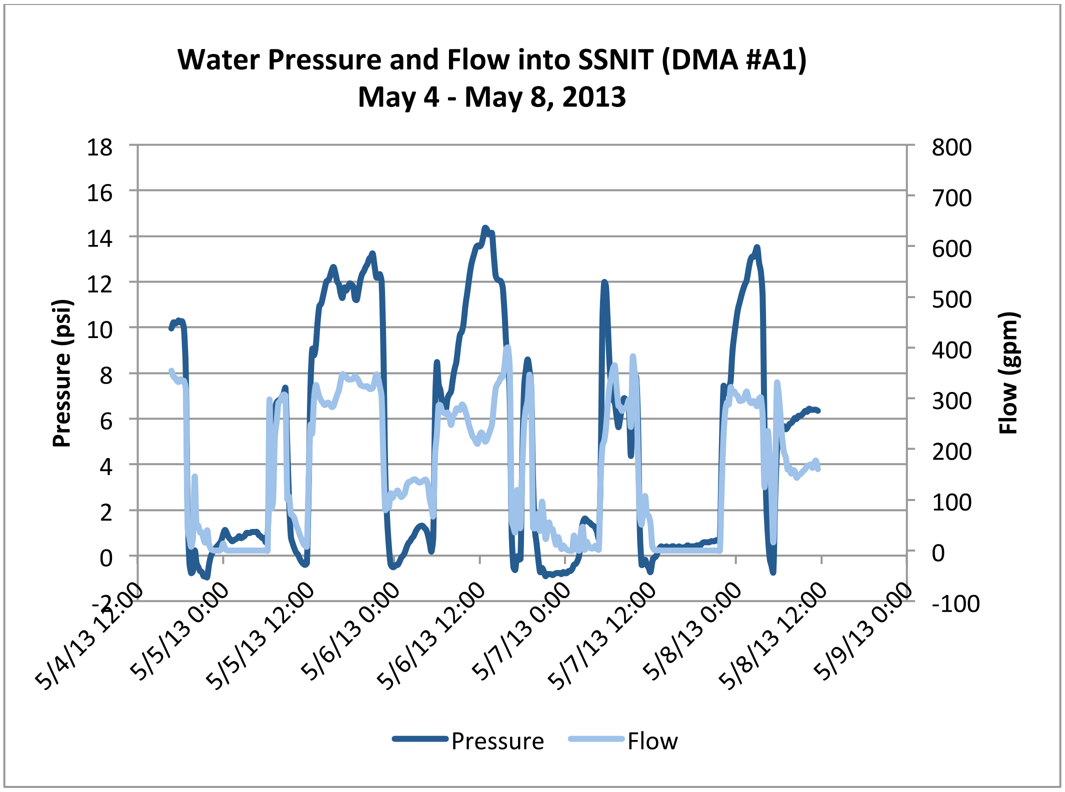

Figure 5–15: Water Pressure and Flow Data for SSNIT

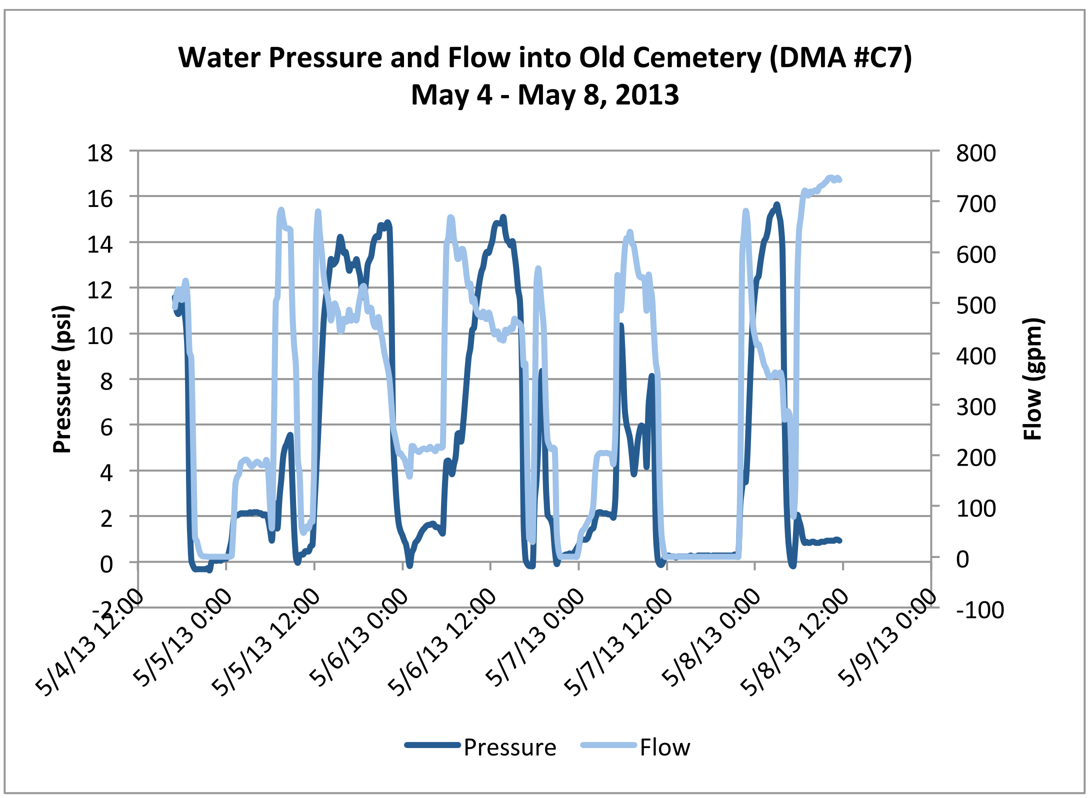

Figure 5–16: Water Pressure and Flow Data for Old Cemetery

In both neighborhoods, flow and pressure vary cyclically over the course of the four days, with positive flow and pressure during daytime hours, and low flow or negative pressure during nighttime hours. Overall, both neighborhoods show intermittent flow and pressure, but SSNIT has significantly worse performance in terms of pressure variation. Water pressure in SSNIT drops to negative values for 18% of the time monitored, while in Old Cemetery pressure is negative for only 6% of the time monitored. Total flow into SSNIT is much less than that into Old Cemetery, but without knowing the population of each neighborhood, it is impossible to say whether one neighborhood is better served with water per capita than another. Neither neighborhood ever reaches the minimum pressure prescribed by the US EPA of 20 psi. For the complete dataset, see Appendix G.

6. Discussion

6.1. GWCL Water Quality Data

GWCL records show that water quality at the treatment plant outflow meets or exceeds international requirements, such as WHO guidelines of 0 cfu/100 mL for *E. coli*, as well as national Ghanaian standards (Ghana Standards Board (GSB) 2008). Water quality in the distribution system is also adequate according to GWCL's monthly data summary reports, although somewhat degraded compared to the samples taken at the treatment plant. This trend is particularly clear in the case of chlorine residual data. According to the GWCL dataset, chlorine residual decreased on average from 1.34 mg/L at the treatment plant, to 0.28 mg/L in the distribution system, a 78% reduction. The figure below shows the percent reduction in average chlorine residual between the treatment plant samples and the distribution system samples.

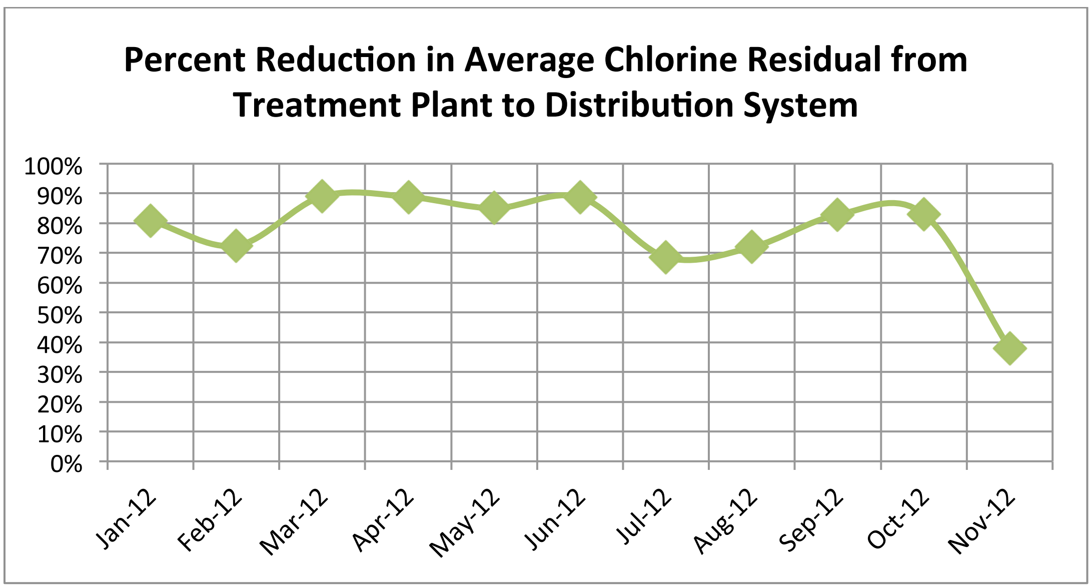

Figure 6–1: Percent Reduction in Average Chlorine Residual from Treatment Plant to Distribution System

Low or nonexistent chlorine residuals do not necessarily indicate that water is bacteriologically contaminated. However, water with some detectable chlorine residual is desirable in the distribution system to guard against re-contamination (US EPA 2006). Chlorine decay is expected within the system, due to water age, presence of organic particles in the pipes, biofilms on pipe walls, etc. Chlorine decay can be modeled using a first order decay expression but the decay constant will differ for each water system. The US EPA recommends conducting simulated distribution system testing to determine the decay rate of the bulk water, as well as conducting testing using portions of piping to account for decay at the pipe walls (US EPA 2006). This type of testing was not performed for the Tamale system, and therefore the chlorine decay characteristics for the system are unknown. Without knowledge of the decay characteristics it is not possible to determine whether the chlorine decay seen between the treatment plant outlet and the distribution system is due primarily to water age or to increased chlorine demand due to contamination.

All samples taken at the treatment plant and the distribution system by GWCL were negative for *E. coli*. The US EPA requires systems to maintain chlorine residuals of at least 0.2 mg/L in the distribution system in order to prevent bacteriological contamination (U.S. Environmental Protection Agency 1989). With an average chlorine residual well above 0.2 in the treatment plant samples, the water will be assumed to be coliform free at the plant outflow. In the distribution system, the average chlorine residual was 0.28 mg/L with 5 months out of 11 resulting in a mean chlorine residual below 0.2 mg/L. Every month's minimum residual was below 0.2 mg/L. Therefore, while there is no direct indication that the water is contaminated, it cannot be assumed that the water in the distribution system is free of bacteria as would be indicated by the total coliform test. Furthermore, GWCL staff indicated there are continuing issues with leakages in the system and several users reported recent leakages in their neighborhoods during the surveys.

Figure 6–2: Broken pipe in Old Cemetery neighborhood (indicating a possible route of contamination)

6.2. Household Surveys

6.2.1. Household Storage Practices

The impact of safe storage on water quality has been repeatedly confirmed through studies and interventions (Mintz, Reiff and Tauxe 1995). In 2009 the CDC and USAID published a fact sheet summarizing recommendations for safe water storage (CDC, USAID 2009). The three key recommendations for safe storage containers were as follows:

1) The container should have a small opening with a lid to discourage users from placing items in the container (such as hands, ladles, etc.), which may be contaminated.

2) The container should have a spigot or other small opening to dispense water without the use of hands or bowls, which may be contaminated.

3) The container should be of a size appropriate for the household water treatment method in use, with instructions for the treatment and cleaning method attached to the container.

None of the containers observed had instructions for treatment and cleaning attached to them and very few households practiced additional household water treatment. Therefore, only the first two recommendations will be evaluated.

Of the storage containers observed during the household surveys, only jerry cans, poly tanks, and steel tanks met the first two criteria listed above. Although the poly tanks and steel tanks had large enough openings for hands to be inserted the tanks themselves were large enough to discourage anyone climbing on top of them to make use of those openings. All other types of storage observed had large openings and no spigot for dispensing water. Figure 6-3 shows the distribution of the different types of storage containers. Note that this data simply counts whether or not a type of container was present and does not specify how many containers of each type or the volume of water stored by each type of container. Containers that meet the recommended criteria are classified as "Safe" in the figure, while containers that do not meet the recommended criteria are classified as "Unsafe" in the figure.

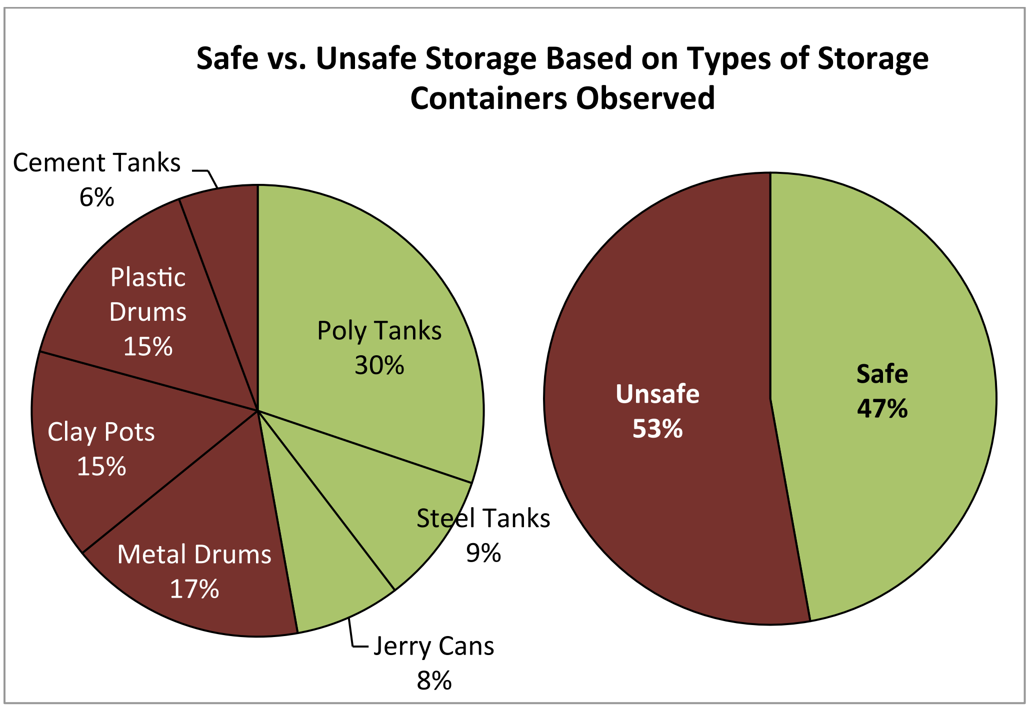

Figure 6–3: Safe vs. Unsafe Storage Based on Types of Storage Containers Observed

6.2.2. Continuity of Water Supply

Survey answers to the question "How often is water flowing from the piped supply?" varied significantly from person to person and neighborhood to neighborhood based on user perceptions of the water supply. Separating out each neighborhood's answers allows a clearer view of the variability within each neighborhood, rather than the city as a whole, as shown in the following figure.

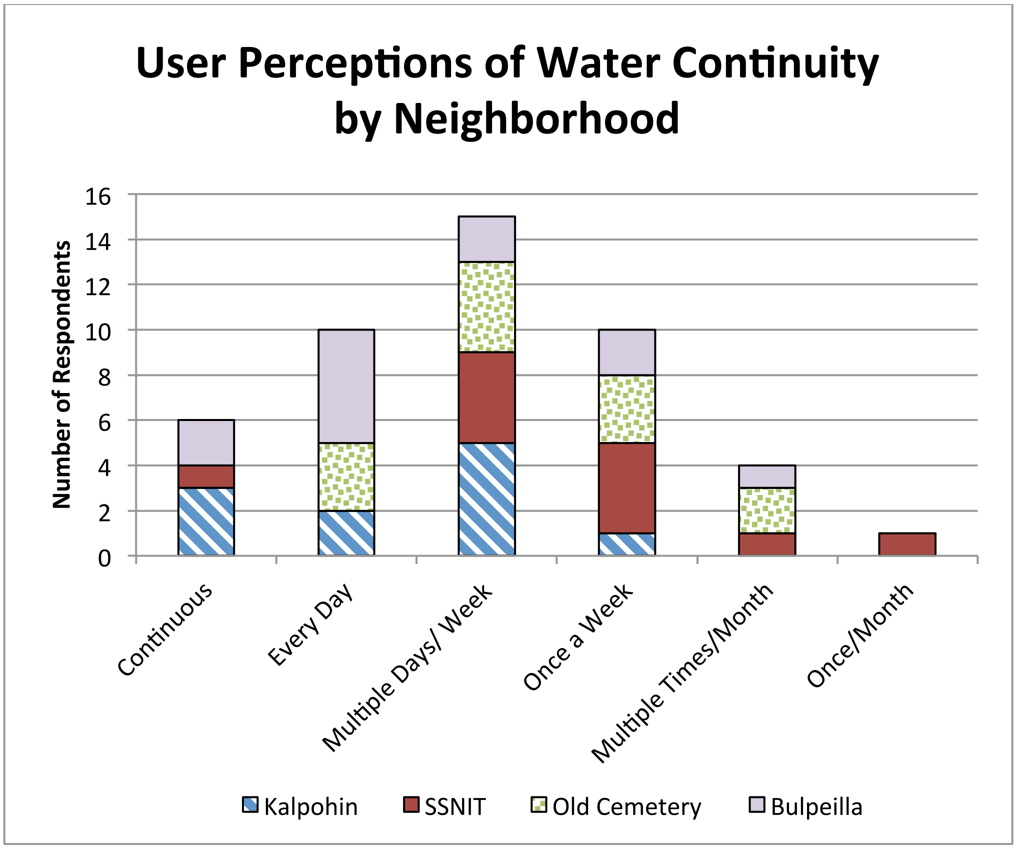

Figure 6–4: User Perceptions of Water Continuity by Neighborhood

As shown in figure 6-4, users in each neighborhood gave a range of answers. Bulpeila and Old Cemetery generally showed a higher perception of the continuity of the water, with most respondents answering that water was running continuously or multiple days per week. SSNIT residents had the poorest perception of their water continuity, with most reporting that water was running less frequently than every day. Kalpohin residents reported that water continuity was very high, with most reporting that the water was running continuously or at least on multiple days per week. For the Bulpeila, Old Cemetery, and SSNIT data sets, responses mimic a roughly normal distribution, with a central peak around the most common response for each neighborhood. Although this is a very small dataset, this pattern implies that the most common answer is likely the most accurate, with variances from the modal value reflecting differences in user perceptions among a population. The fact that the Kalpohin data does not show this pattern, combined with the overall vagueness of the answers, implies that the Kalpohin dataset is the least reliable of the four on this particular topic.

6.3. Household Water Quality Data

The samples taken from household water storage resulted in an average chlorine residual of 0.097 mg/L. This represents a 67% reduction from the average chlorine residual found in the distribution system samples taken by GWCL. One mechanism for this decay is water age. In the interviews, most respondents reported that their piped water supply was running multiple times per week, meaning average water age in the storage vessels was likely 3-4 days.

In addition to water age, chlorine residual can decrease due to recontamination of water during collection or storage. As shown previously, 73% of the household samples tested positive for total coliforms and 33% tested positive for *E. coli*. There is no data from GWCL on total coliforms in the distribution system, so the presence of these bacteria does not definitively show that water quality has decreased in the households rather than the system itself. The presence of *E. coli* in the stored water samples however indicates that water quality has degraded between the distribution system samples and household storage since all distribution system samples were negative for *E. coli* and 33% of household storage samples tested positive for *E. coli*.

7. Conclusions and Recommendations

7.1. Objective 1: Water Quality Degradation in the Distribution System

Two water quality parameters were used to track water quality in the distribution system: free chlorine residual and *E. coli.* Comparing results from the Dalun-Nawuni WTP and the distribution system show a clear degradation in water quality, as evidenced by diminishing free chlorine. On average, free chlorine residual values decreased by 78% between the Dalun-Nawuni WTP outlet and the sample sites in the distribution system. Further work is needed to determine if this degradation is due primarily to aging of the water in the distribution system or contamination through back-pressure situations. No *E. coli* was detected in either the treatment plant outlet samples or the distribution systems samples so there is no evidence of bacteriological contamination based on this dataset. However, it is unknown where samples were collected in the distribution system, so it is possible that these samples do not represent the most vulnerable areas of the system.

7.2. Objective 2: Water Quality in Household Storage Containers

Free chlorine residual, total coliform, and *E. coli* were tested in household storage containers in four different neighborhoods in Tamale. Free chlorine residual levels were found to be below 0.2 mg/L in 92% of samples tested, the level considered "safe" by the USEPA and WHO. Without further observations of storage behavior, it is not possible to know how much of this chlorine decay is due to water age vs. contamination by the users. However, evidence of contamination was seen in the bacteriological results, with 83% of samples having detectable levels of total coliform, and 33% of samples having detectable levels of *E. coli*. It is possible that the water already contained bacteria prior to collection, but observations of unsanitary storage practices during the household surveys strongly imply that the water is being contaminated by users after collection. These practices included storing water in open containers, dipping hands in containers, and using containers that appeared dirty.

7.3. Objective 3: Modeling the Distribution System

Currently, there are no commercial models available suitable for modeling an intermittent distribution system. However, there are several models in development by researchers. In addition, it is possible to approximate an intermittent system using a combination of conventional modeling tools such as EPANET and SWMM. This approach requires inputs of: GIS data of the network, customer demand information, and flow and pressure data for calibration. While GIS data and flow and pressure data were provided by GWCL, the final pieces of information were sent in May 2013, too late to attempt to calibrate and run a model within the academic year. However, the data can provide an excellent starting point for future research using a hydraulic model.

7.4. Recommended Improvements to Household Storage

Although safe storage practices alone will not totally eliminate the risk of contamination in household water supplies, there is clearly great potential for improving the design of household storage vessels and hygienic behavior in Tamale. Through their household water treatment and safe storage (HWTS) network the WHO has worked to publish literature advocating safe water storage in developing countries[10]. Publications from the network include fact sheets, research papers, and examples of national action plans. Local NGOs in Tamale could make use of these resources and work in collaboration with GWCL to educate customers about safe storage practices and distribute safe storage containers.

One NGO in particular, Pure Home Water (PHW) is already working in the Tamale area to produce and distribute ceramic water filters and safe storage containers to residents, especially targeting those without a piped water connection. (For more information on PHW, refer to Cheng 2013). It is recommended that this group consider adding safe storage education and sale of safe storage containers to their scope of work. While some users interviewed were aware of the importance of safe storage practices, many were not and were surprised to learn during the course of the interview that it was possible for their piped water supply to become contaminated.

7.5. Recommended Improvements to the Distribution System

There are two major approaches that are considered to improve intermittent supply systems. One approach is to reduce intermittency by increasing supply and reducing non-revenue water. The other approach is to assume the system will stay intermittent and take measures to prevent contamination in the system (Cabrera-Bejar and Tzatchkov 2009). It is recommended that both approaches be carried out. In the long term several steps should be taken to reduce the intermittency of the distribution system. Reducing intermittency will help improve water quality in the system by reducing low pressure episodes that could lead to contamination. Reducing intermittency will also decrease the need for users to store water in their homes and decrease the risk of contamination through home storage.

There are several major, interrelated causes for intermittency in the Tamale system. According to conversations with GWCL staff, one of the most urgent problems is that of non-revenue water in the system. Large percentages of the water supply are lost each month through physical losses (leaks) as well as commercial losses (water that is not paid for). If non-revenue water could be reduced, there would be more water available for the system and the network could become more continuous (although it would still likely be intermittent). With the 2008 expansion of the Dalun-Nawuni treatment plant, its maximum capacity is now 44 MLD. Given the population estimate of 371,351 people (Ghana Statistical Services 2012) this plant would be able to supply 118 liters per person per day if every household was connected to the system and there was minimal non-revenue water. The UN recommends that each person have access to 20-50 liters per day for cooking, cleaning and drinking so 118 liters per person would be more than adequate[11]. In order to accomplish this, more resources need to be allocated towards fixing leaks and tracking down illegal connections. Improving maintenance on the system and reducing non-revenue water will also help prevent contamination in the short term. In addition, efforts need to be made to improve the reliability of the treatment plant. GWCL employees say that power outages at the plant are a common cause of interruption and residents report instances of prolonged water outages due to maintenance issues.

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[10] http://www.who.int/household_water/network/en/

[11] http://www.unwater.org/statistics_san.html

7.6. Future Work Needed

At the outset, the purpose of this research was to show the connections between intermittent water supply, household storage, and household water quality. This is a large topic, and this research was more exploratory than definitive. This study has helped refine the questions that need to be answered and give direction to future research. The surveys and water quality testing conducted for this study clearly showed that there is bacteriological contamination in household drinking water, as measured by chlorine residual, total coliform, and *E. coli*, even for those households directly connected to the piped water system. However, the sample size was small (40 households) and data collected was more qualitative than quantitative. This study began the process of documenting the system and discovering the water quality and performance issues in the distribution system and households, but much more work could be done. The following research projects are proposed for future studies (by MIT M. Eng. students or others):

1. Household Water Quality and Storage Practices

Further work needs to be done collecting data from households connected to piped water supply in order to more thoroughly define the problem of household water contamination in Tamale. A more detailed study would include mapping households surveyed and comparing spatial data with the GIS data of the piped network in order to identify patterns. This study should also include sampling when water is flowing in pipes in order to capture the quality of the water before it enters a user's household storage system. More detailed surveys should be conducted of users' water storage practices to more fully understand the connection between storage and handling practices and water quality.

2. Hydraulic Modeling of Contamination Caused by Intermittent Water Supply

This project would involve detailed hydraulic modeling of the system to discover how much of the system is under low pressure conditions. Once this is known, an estimate could be made of the number of fractures or breaches in the system and a model of contamination could be developed. Ideally this model would account for dry as well as rainy season conditions. GWCL has a model of the piped water system but there is no modeler currently staffed in the Tamale office.

3. Modeling Chlorine Decay in the Tamale Distribution System

This project would involve collecting data on chlorine decay in the bulk water, in order to understand if decay is occurring primarily due to water age, contamination in the distribution system, or contamination in household storage. This approach could involve simulated distribution system tests using the treatment plant outlet water as well as removing pipe coupons from the system and testing for biofilms and other sources of chlorine demand.

4. Historical Water Quality Data Compilation and Analysis

This project would involve in-depth research of existing GWCL records. At the moment, the only data that appears to be entered electronically is the sample month, the general area where the sample was taken, and the result. However, there are years of records stored at the GWCL water quality laboratory – hand written notebooks that contain more detailed information such as date and time of samples and more precise locations. This data could be converted to electronic format and mapped and analyzed for patterns pointing to causes of water contamination. This could be an extremely useful exercise as the data is already available, but has not been analyzed in a systematic way.

These four projects could be conducted separately or concurrently and in individual neighborhoods or the city as a whole. As more of the world moves towards “improved” water supply with piped water networks it is of the utmost importance to study these systems and ensure that “improved” water is actually an improvement in terms of public health.

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Appendix A: Hach Pocket Colorimeter II Total Chlorine Method

Adapted from: Hach **POCKET COLORIMETER II** ANALYSIS SYSTEMS INSTRUCTION MANUAL, 2009

1. Fill a 10-mL cell with sample (the blank). Cap.
2. Press the POWER key to turn the meter on. The arrow should indicate the low range channel (LR).
3. Remove the meter cap. Wipe excess liquid and finger prints off sample cell. Place the blank in the cell holder with the diamond mark facing the keypad. Fit the meter cap over the cell compartment to cover the cell.
4. Press ZERO/SCROLL. The display will show "----" then "0.00". Remove the blank from the cell holder.
5. Fill a second 10-mL cell to the 10 mL line with sample.
6. Add the contents of one DPD free Chlorine Powder Pillow to the sample cell (the prepared sample).
7. Cap and shake gently for 20 seconds. Allow the bubbles to dissipate.
8. Wipe excess liquid and fingerprints from the sample cell. Put the prepared sample cell in the cell holder, with the diamond mark facing the keyboard, and then cover the cell with the instrument cap.
9. After one minute, press the READ/ENTER button. The instrument will show "----" followed by the results in mg/L chlorine.

Appendix B: MPN vs. CFU Summary
Provided by Sharon Muhilly of IDEXX via email on 5/16/13

MPN vs. CFU

MPN vs. CFU: Is there a difference different between the two? A simple answer is that the use of either term is based on the method the lab uses for the detection of total or fecal coliforms, *E.coli*, enterococci or heterotrophic bacteria.

1. **Depending on the test method used, MPN (Most Probable Number) or CFU (Colony Forming Unit) is the label or unit associated with a numerical result.**

   Coliform/*E.coli* methods such as Multiple Tube Fermentation and Colilert*, either via the Quanti-Tray* or Quanti-Tray*/2000 or when testing in predispensed Colilert tubes, report the quantitative results as an MPN/100mL. An MPN Table is statistically generated. The Membrane Filtration methods report results as CFU/100ml. MPN or CFU methods which closely correlate would have a numerical result within the 95% Confidence Limit of each result, however the actual number would be assigned either as an MPN/100ml or CFU/100ml depending on the test method.

   Example:

CFU	MF	MF
	lower conf limits	upper conf limits
10	4.7	18.4
12	6.2	21
16	9.4	26
20	12.2	30.8

MPN	Q-Tray/2000	Q-Tray/2000
	lower conf limits	upper conf limits
9.7	4.5	17.2
11.5	6	20.1
15.5	8.6	25.1
20.1	12.4	31.8

   SimPlate* for HPC reports results in MPN/mL and the HPC Plate Count Agar (PCA) Pour Plate Method report results in CFU/mL. IDEXX* internal testing and field evaluations of SimPlate for HPC have shown a correlation (r=0.95) between the SimPlate Method reported as MPN/mL and the Plate Count Agar (PCA) Pour Plate Method reported as CFU/mL.

2. **Modeling the Relationship Between Most Probable Number (MPN) and Colony-Forming Unit (CFU) Estimates of Fecal Coliform Concentration**

   Andrew D. Gronewold[a] and Robert L. Wolpert[b], Duke University - *April 2008*

   [a]Nicholas School of the Environment and Earth Sciences, Box 90328, Duke University,

   Durham, NC 27708-0328, USA

   [b]Department of Statistical Science, Duke University, Durham, NC 27708, USA

*Colilert, Quanti-Tray, and SimPlate are trademarks or registered trademarks of IDEXX Laboratories, Inc. in the United States and/or other countries. All other marks are the property of their respective holders.

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IDEXX

MPN vs. CFU

Most probable number (MPN) and colony-forming-unit (CFU) are two estimates of fecal coliform bacteria concentration commonly used as measures of water quality in shellfish harvesting waters and recreational waters. The MPN is the maximum likelihood estimate (or MLE) of the true fecal coliform concentration based on counts of non-sterile tubes in serial dilution of a sample aliquot, indicating bacterial metabolic activity. The CFU is the MLE of the true fecal coliform concentration based on the number of bacteria colonies emerging on a growth plate after inoculation from a sample aliquot. Each estimating procedure has intrinsic variability and is subject to additional uncertainty arising from minor variations in experimental protocol.

3. **Email correspondence from Dr. Seppo Nimela, Biostatistician; University of Helsinki, Helsinki, Finland**

Many comparative trials have shown adequate equivalence between the results of colony count methods and corresponding MPN methods. The issue is therefore mostly of an unfortunate original choice of expression rather than a scientific argument. It is, of course, a little 'out of style' to enter MPN values in a column called 'cfu' but factually it makes no difference. After all, both cfu and MPN are estimates of the same thing which is the concentration of viable target particles in the sample. The names cfu and MPN basically refer to the technique employed in estimation. Neither of the results is guaranteed to be the right number of viable particles, as both are only estimates. The method of estimation can be indicated with each result.

The origin of the trouble is the difficulty to observe the number of viable microbial particles directly. Therefore, indirect detection methods are employed. The two basic principles for quantification in microbiology are the colony method and the liquid-culture method. The result of the former is usually called 'cfu'. The result of the liquid culture method is called MPN, 'the most probable number' (of viable particles) to indicate that mathematical probability calculations are involved. Originally the term 'cfu' was chosen to indicate that the colonies observed did not necessarily arise from individual bacterial cells but from particles or 'units' composed of possibly more than one cell.

An analogous example can be imagined in chemistry. One might, for instance, have the choice to determine the concentration of substance X by a gravimetric or a colorimetric method. It is the same target but the techniques of evaluation are different. If the result column should happen to be named 'gravimetric X', then it would certainly be difficult to enter values of X by colorimetric analysis in the same column. But if the column was called 'Concentration of X', then it would make no difference.

4. **Reporting Units for Bacteria Limits in Water Quality Permits and Authorizations**

Texas Commission of Environmental Quality

Correspondence with Dr. J Steven Gibson; Team Leader, Quality Assurance Team [Laboratory Accreditation, Quality Assurance, and Calibration Laboratory Groups] 5/27/11

Bacteria levels may be reported using two different units, colony forming units (CFU) and most probable number (MPN). The two different units are the results of two different analyses, both of which are EPA approved methods. The Water Quality Division recommends that the Regional Offices and the Enforcement Division accept both CFU and MPN as valid measurements for bacteria limits in water quality permits and authorizations.

Appendix C: IDEXX Quanti-Tray Method

Adapted from IDEXX Overview Instructions (2010) available on manufacturer's website. http://www.idexx.com/resource-library/water/quanti-tray-2000-procedure-en.pdf

IDEXX Quanti-Tray*/2000

English Version

Introduction

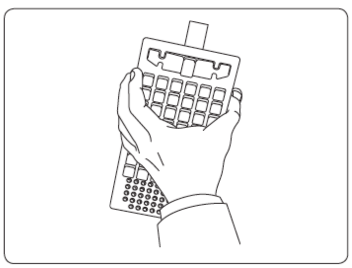
IDEXX Quanti-Tray/2000 is designed to give quantitated bacterial counts of 100 mL samples using IDEXX reagent products. Add the reagent/sample mixture to a Quanti-Tray/2000, seal it in a Quanti-Tray Sealer and incubate per the reagent instructions. Count the number of positive large and small wells and use the Most Probable Number (MPN) Table attached to determine the MPN.

Contents

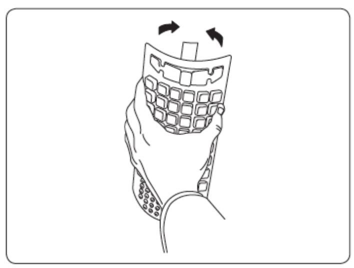
This package contains sterile Quanti-Tray/2000s.

User Instructions

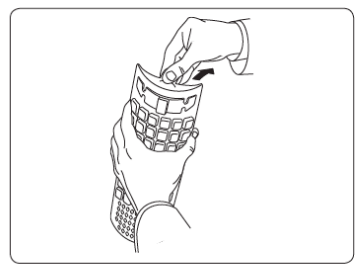
1. Use one hand to hold a Quanti-Tray upright with the well side facing the palm.



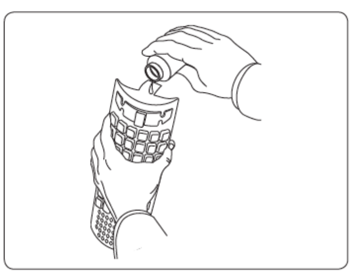
2. Squeeze the upper part of the Quanti-Tray so that the Quanti-Tray bends toward the palm.



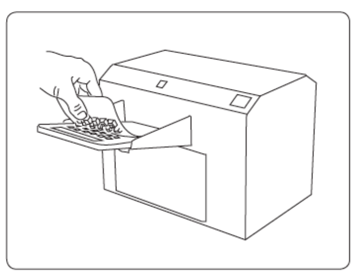
3. Gently pull foil tab to separate the foil from the tray. Avoid touching the inside of the foil or tray.



4. Pour the reagent/sample mixture directly into the Quanti-Tray, avoiding contact with the foil tab. Tap the small wells 2–3 times to release any air bubbles. Allow foam to settle.



5. Place the sample-filled Quanti-Tray onto the Quanti-Tray/2000 rubber insert of the Quanti-Tray Sealer with the well side (plastic) of the Quanti-Tray facing down.



6. Seal according to the Quanti-Tray Sealer instructions.
7. Incubate according to reagent instructions.
8. Count large and small positive wells and refer to the Quanti-Tray/2000 MPN table to find the MPN.†
9. Dispose of media in accordance with good laboratory practices.

Appendix D: GWCL Water Quality Data

Dalun-Nawuni Treatment Plant Data										
Month	Parameter	No of Samples Required	Actual No of samples	Min	Max	Mean	Median	Modal value	Std. Dev.	No of Samples Complying
Jan-12	Aluminium	1	1	0.042	0.042	0.042	0.042			1
Feb-12	Aluminium	1	1	0.123	0.123	0.123	0.123			1
Mar-12	Aluminium	1	1	0.237	0.237	0.237	0.237			0
Apr-12	Aluminium	1	1	0.044	0.044	0.044	0.044			1
May-12	Aluminium	1	1	0.105	0.105	0.105	0.105			1
Jun-12	Aluminium	1	1	0.374	0.374	0.374	0.374			0
Jul-12	Aluminium	1	1	0.463	0.463	0.463	0.463			0
Aug-12	Aluminium	1	1	0.248	0.248	0.248	0.248			0
Sep-12	Aluminium	1	1	1.54	1.54	1.54	1.54			0
Oct-12	Aluminium	1	1	0.174	0.174	0.174	0.174			1
Nov-12	Aluminium	1	1	0.299	0.299	0.299	0.299			0
Jan-12	Ammonia	1	1	0	0	0	0			1
Feb-12	Ammonia	1	1	0.92	0.92	0.92	0.92			1
Mar-12	Ammonia	1	1	0.08	0.08	0.08	0.08			1
Apr-12	Ammonia	1	1	0.05	0.05	0.05	0.05			1
May-12	Ammonia	1	1	0	0	0	0			1
Jun-12	Ammonia	1	1	0.01	0.01	0.01	0.01			1
Jul-12	Ammonia	1	1	0.24	0.24	0.24	0.24			1
Aug-12	Ammonia	1	1	0.01	0.01	0.01	0.01			1
Sep-12	Ammonia	1	1	0	0	0	0			1
Oct-12	Ammonia	1	1	0	0	0	0			1
Nov-12	Ammonia	1	1	0.12	0.12	0.12	0.12			1
Jan-12	Arsenic	1	1	0.007	0.01	0.007	0.007			1
Feb-12	Arsenic	1	1	0	0.92	0	0			1
Mar-12	Arsenic	1	1	0	0.08	0	0			1
Apr-12	Arsenic	1	1	0.003	0.05	0.003	0.003			1
May-12	Arsenic	1	1	0	0.002	0	0			1
Jun-12	Arsenic	1	1	0	0.01	0	0			1
Jul-12	Arsenic	1	1	0	0.24	0	0			1
Aug-12	Arsenic	1	1	0	0.01	0	0			1
Sep-12	Arsenic	1	1	0	0	0	0			1
Oct-12	Arsenic	1	1	0	0.001	0	0			1
Nov-12	Arsenic	1	1	0	0.12	0	0			1
Jan-12	Chlorine	1	1	20	16	20	20			1
Feb-12	Chlorine	1	1	13	15	13	13			1
Mar-12	Chlorine	1	1	13	16	13	13			1
Apr-12	Chlorine	1	1	20	15	20	20			1

Dalun-Nawuni Treatment Plant Data										
Month	Parameter	No of Samples Required	Actual No of samples	Min	Max	Mean	Median	Modal value	Std. Dev.	No of Samples Complying
May-12	Chlorine	1	1	18	19	18	18			1
Jun-12	Chlorine	1	1	19	22	19	19			1
Jul-12	Chlorine	1	1	18	23	18	18			1
Aug-12	Chlorine	1	1	20	26	20	20			1
Sep-12	Chlorine	1	1	23	23	23	23			1
Oct-12	Chlorine	1	1	27	21	27	27			1
Nov-12	Chlorine	1	1	34	22	34	34			1
Jan-12	Colour	93	93	5	5	5	5	5	0	93
Feb-12	Colour	93	82	5	5	5	5	5	0	82
Mar-12	Colour	93	87	5	5	5	5	5	0	87
Apr-12	Colour	93	78	5	5	5	5	5	0	78
May-12	Colour	93	88	5	5	5	5	5	0	88
Jun-12	Colour	93	77	5	5	5	5	5	0	77
Jul-12	Colour	93	89	5	5	5	5	5	0	89
Aug-12	Colour	93	89	5	5	5	5	5	0	89
Sep-12	Colour	93	83	5	5	5	5	5	0	83
Oct-12	Colour	93	90	5	5	5	5	5	0	90
Nov-12	Colour	93	88	5	5	5	5	5	0	88
Jan-12	E-coli	31	31	0	0	0	0	0	0	31
Feb-12	E-coli	31	29	0	0	0	0	0	0	29
Mar-12	E-coli	31	31	0	0	0	0	0	0	31
Apr-12	E-coli	31	31	0	0	0	0	0	0	31
May-12	E-coli	31	31	0	0	0	0	0	0	31
Jun-12	E-coli	31	30	0	0	0	0	0	0	30
Jul-12	E-coli	31	31	0	0	0	0	0	0	31
Aug-12	E-coli	31	31	0	0	0	0	0	0	31
Sep-12	E-coli	30	30	0	0	0	0	0	0	30
Oct-12	E-coli	30	31	0	0	0	0	0	0	31
Nov-12	E-coli	30	30	0	0	0	0	0	0	30
Jan-12	Fluoride	1	1	0	0	0	0			1
Feb-12	Fluoride	1	1	0.73	0.73	0.73	0.73			1
Mar-12	Fluoride	1	1	0.26	0.26	0.26	0.26			1
Apr-12	Fluoride	1	1	0	0	0	0			1
May-12	Fluoride	1	1	0	0	0	0			1
Jun-12	Fluoride	1	1	0	0	0	0			1
Jul-12	Fluoride	1	1	0	0	0	0			1
Aug-12	Fluoride	1	1	0	0	0	0			1
Sep-12	Fluoride	1	1	0	0	0	0			1
Oct-12	Fluoride	1	1	0	0	0	0			1

Dalun-Nawuni Treatment Plant Data										
Month	Parameter	No of Samples Required	Actual No of samples	Min	Max	Mean	Median	Modal value	Std. Dev.	No of Samples Complying
Nov-12	Fluoride	1	1	0	0	0	0			1
Jan-12	Hardeness	1	1	16	16	16	16			1
Feb-12	Hardeness	1	1	15	15	15	15			1
Mar-12	Hardeness	1	1	16	16	16	16			1
Apr-12	Hardeness	1	1	15	15	15	15			1
May-12	Hardeness	1	1	19	19	19	19			1
Jun-12	Hardeness	1	1	22	22	22	22			1
Jul-12	Hardeness	1	1	23	23	23	23			1
Aug-12	Hardeness	1	1	26	26	26	26			1
Sep-12	Hardeness	1	1	23	23	23	23			1
Oct-12	Hardeness	1	1	21	21	21	21			1
Nov-12	Hardeness	1	1	22	22	22	22			1
Jan-12	Iron	1	1	0.03	0.03	0.03	0.03			1
Feb-12	Iron	1	1	0	0	0	0			1
Mar-12	Iron	1	1	0.03	0.03	0.03	0.03			1
Apr-12	Iron	1	1	0.08	0.08	0.08	0.08			1
May-12	Iron	1	1	0.05	0.05	0.05	0.05			1
Jun-12	Iron	1	1	0.04	0.04	0.04	0.04			1
Jul-12	Iron	1	1	0.1	0.1	0.1	0.1			1
Aug-12	Iron	1	1	0.05	0.05	0.05	0.05			1
Sep-12	Iron	1	1	0.02	0.02	0.02	0.02			1
Oct-12	Iron	1	1	0.05	0.05	0.05	0.05			1
Nov-12	Iron	1	1	0.05	0.05	0.05	0.05			1
Jan-12	Manganese	1	1	0.138	0.138	0.138	0.138			0
Feb-12	Manganese	1	1	0	0	0	0			1
Mar-12	Manganese	1	0	0	0					0
Apr-12	Manganese	1	0	0	0					0
May-12	Manganese	1	1	0	0	0	0			1
Jun-12	Manganese	1	1	0.017	0.017	0.017	0.017			1
Jul-12	Manganese	1	1	0	0	0	0			1
Aug-12	Manganese	1	0	0	0					0
Sep-12	Manganese	1	0	0	0					0
Oct-12	Manganese	1	0	0	0					0
Nov-12	Manganese	1	0	0	0					0
Jan-12	Nitrate	1	1	0.04	0.04	0.04	0.04			1
Feb-12	Nitrate	1	1	0.01	0.01	0.01	0.01			1
Mar-12	Nitrate	1	1	0.06	0.06	0.06	0.06			1
Apr-12	Nitrate	1	1	0.1	0.1	0.1	0.1			1
May-12	Nitrate	1	1	0	0	0	0			1

Dalun-Nawuni Treatment Plant Data										
Month	Parameter	No of Samples Required	Actual No of samples	Min	Max	Mean	Median	Modal value	Std. Dev.	No of Samples Complying
Jun-12	Nitrate	1	1	2	2	2	2			1
Jul-12	Nitrate	1	1	0.005	0.005	0.005	0.005			1
Aug-12	Nitrate	1	1	0.2	0.2	0.2	0.2			1
Sep-12	Nitrate	1	1	0	0	0	0			1
Oct-12	Nitrate	1	1	0.4	0.4	0.4	0.4			1
Nov-12	Nitrate	1	1	0.7	0.7	0.7	0.7			1
Jan-12	Nitrite	1	1	0.01	0.01	0.01	0.01			1
Feb-12	Nitrite	1	1	0.006	0.006	0.006	0.006			1
Mar-12	Nitrite	1	1	0.003	0.003	0.003	0.003			1
Apr-12	Nitrite	1	1	0.003	0.003	0.003	0.003			1
May-12	Nitrite	1	1	0.002	0.002	0.002	0.002			1
Jun-12	Nitrite	1	1	0.001	0.001	0.001	0.001			1
Jul-12	Nitrite	1	1	0	0	0	0			1
Aug-12	Nitrite	1	1	0.004	0.004	0.004	0.004			1
Sep-12	Nitrite	1	1	0	0	0	0			1
Oct-12	Nitrite	1	1	0.001	0.001	0.001	0.001			1
Nov-12	Nitrite	1	1	0.001	0.001	0.001	0.001			1
Jan-12	pH	93	93	6.9	7.46	7.131828	7.1	7.3	0.1485	93
Feb-12	pH	93	82	6.92	7.6	7.220488	7.21	7.3	0.1606	82
Mar-12	pH	93	87	6.99	7.43	7.171839	7.16	7.3	0.1135	87
Apr-12	pH	93	78	6.82	717	16.32013	7.25	7.3	80.367	77
May-12	pH	93	88	6.96	7.5	7.22	7.2	7.3	0.1372	88
Jun-12	pH	93	77	6.4	7.53	6.94	6.93	6.8	0.2539	76
Jul-12	pH	93	89	5.5	7.54	6.734607	6.59	6.5	0.3861	79
Aug-12	pH	93	89	6.5	7.7	6.914157	6.9	6.5	0.3228	89
Sep-12	pH	93	83	6.5	7.62	7.136024	7.2	7.6	0.3547	83
Oct-12	pH	93	90	6.7	7.83	7.272822	7.3	7.6	0.2589	90
Nov-12	pH	93	88	6.37	7.6	7.028417	7.045	7.25	0.2255	87
Jan-12	R-chlorine	93	93	1.14	2	1.954731	2	2	0.1265	93
Feb-12	R-chlorine	93	81	1.2	2	1.95963	2	2	0.1328	81
Mar-12	R-chlorine	93	87	1.26	2	1.976552	2	2	0.1114	87
Apr-12	R-chlorine	93	78	0.5	2	1.402564	1.5	1.5	0.4102	78
May-12	R-chlorine	93	88	0.79	1.78	1.032045	1	1	0.137	88
Jun-12	R-chlorine	93	77	0.64	2	1.325325	1	1	0.4308	77
Jul-12	R-chlorine	93	89	0.74	2.08	1.160562	1	1	0.3501	89
Aug-12	R-chlorine	93	89	1	1.54	1.012697	1	1	0.0693	89
Sep-12	R-chlorine	93	82	1	2	1.02378	1	1	0.1401	82
Oct-12	R-chlorine	93	90	1	1	1	1	1	0	90
Nov-12	R-chlorine	93	88	1	1	1	1	1	0	88

Dalun-Nawuni Treatment Plant Data										
Month	Parameter	No of Samples Required	Actual No of samples	Min	Max	Mean	Median	Modal value	Std. Dev.	No of Samples Complying
Jan-12	Sulphate	1	1	16	16	16	16			1
Feb-12	Sulphate	1	1	22	22	22	22			1
Mar-12	Sulphate	1	1	17	17	17	17			1
Apr-12	Sulphate	1	1	27	27	27	27			1
May-12	Sulphate	1	1	28	28	28	28			1
Jun-12	Sulphate	1	1	39	39	39	39			1
Jul-12	Sulphate	1	1	37	37	37	37			1
Aug-12	Sulphate	1	1	40	40	40	40			1
Sep-12	Sulphate	1	1	43	43	43	43			1
Oct-12	Sulphate	1	1	33	33	33	33			1
Nov-12	Sulphate	1	1	32	32	32	32			1
Jan-12	Total Disolved S	1	1	52.3	52.3	52.3	52.3			1
Feb-12	Total Disolved S	1	1	56.4	56.4	56.4	56.4			1
Mar-12	Total Disolved S	1	1	55.3	55.3	55.3	55.3			1
Apr-12	Total Disolved S	1	1	59.3	59.3	59.3	59.3			1
May-12	Total Disolved S	1	1	59.2	59.2	59.2	59.2			1
Jun-12	Total Disolved S	1	1	61.7	61.7	61.7	61.7			1
Jul-12	Total Disolved S	1	1	71.5	71.5	71.5	71.5			1
Aug-12	Total Disolved S	1	1	60.9	60.9	60.9	60.9			1
Sep-12	Total Disolved S	1	1	65	65	65	65			1
Oct-12	Total Disolved S	1	1	59.2	59.2	59.2	59.2			1
Nov-12	Total Disolved S	1	1	60.2	60.2	60.2	60.2			1
Jan-12	Turbidity	93	93	0	4.97	3.460968	3.53	3.61	0.8519	93
Feb-12	Turbidity	93	82	2	4.44	2.872439	2.88	3.2	0.4367	82
Mar-12	Turbidity	93	87	0.74	3.13	1.84046	1.78	2.34	0.5877	87
Apr-12	Turbidity	93	77	0.4	2.97	1.539091	1.49	1.25	0.508	77
May-12	Turbidity	93	88	0.65	14.17	1.725795	1.445	1.02	1.5302	86
Jun-12	Turbidity	93	77	0.6	13.2	1.550649	1.18	0.99	1.5215	75
Jul-12	Turbidity	93	88	0.94	8.64	2.342273	2.07	2.07	1.2978	84
Aug-12	Turbidity	93	89	0.86	5.36	2.745843	2.78	1.68	0.9362	87
Sep-12	Turbidity	93	83	0.79	5	2.420964	2.22	2.37	0.9093	83
Oct-12	Turbidity	93	90	0.46	5	2.072141	1.73935	1.28	1.0452	90
Nov-12	Turbidity	93	86	1.97	5.4	3.59832	3.74	3.02	0.8836	84

	TAMALE EAST DISTRIBUTION WATER QUALITY ANALYSIS									
MONTH	Parameter	Required No. of samples	Actual No. of Samples	Min	Max	Mean	Median	Modal Value	Std. Dev.	No of Samples Complying
Jan-12	Colour	30	30	0	5.9	3.5066667	3.6	3.6	1.37538291	30
Feb-12	Colour	30	30	0.1	3.9	1.1233333	0.9	0.6	0.84105161	30
Mar-12	Colour	30	30	0.6	5.3	3.3333333	3.95	4.2	1.5152861	30
Apr-12	Colour	30	30	0	1.8	0.7466667	0.65	0	0.54881272	30
May-12	Colour	30	30	0	3.2	1.3966667	1.25	2.4	1.06689473	30
Jun-12	Colour	30	30	0	5.5	1.13	0.7	1	1.38866098	30
Jul-12	Colour	30	30	0	12.4	2.1933333	1.2	0	2.85100507	30
Aug-12	Colour	30	30	0	7	1.7533333	1.4	0	1.79784034	30
Sep-12	Colour	30	30	0	3.4	0.8233333	0.85	1	0.71952251	30
Oct-12	Colour	30	30	0	4	1.07	1	1	0.80135661	30
Nov-12	Colour	30	30	0	6.5	1.4933333	1.05	0	1.58482749	30
Jan-12	E-coli	30	30	0	0	0	0	0	0	30
Feb-12	E-coli	30	30	0	0	0	0	0	0	30
Mar-12	E-coli	30	30	0	0	0	0	0	0	30
Apr-12	E-coli	30	30	0	0	0	0	0	0	30
May-12	E-coli	30	30	0	0	0	0	0	0	30
Jun-12	E-coli	30	30	0	0	0	0	0	0	30
Jul-12	E-coli	30	30	0	0	0	0	0	0	30
Aug-12	E-coli	30	30	0	0	0	0	0	0	30
Sep-12	E-coli	30	30	0	0	0	0	0	0	30
Oct-12	E-coli	30	30	0	0	0	0	0	0	30
Nov-12	E-coli	30	30	0	0	0	0	0	0	30
Jan-12	pH	30	30	6.66	7.48	6.9916667	7.02	6.76	0.16436048	30
Feb-12	pH	30	30	6.63	7.12	6.9343333	6.975	7.01	0.10411146	30
Mar-12	pH	30	30	6.74	7	6.9063333	6.915	6.93	0.04552251	30
Apr-12	pH	30	30	6.93	7.3	7.106	6.97	6.96	0.16458097	30
May-12	pH	30	30	7.28	7.67	7.47	7.465	7.3	0.17696678	30
Jun-12	pH	30	30	6.5	7.6	6.9566667	6.9	6.5	0.38746153	30
Jul-12	pH	30	30	6.5	7.8	6.775	6.7	6.7	0.30926777	30
Aug-12	pH	30	30	6.5	7.6	6.734	6.7	6.6	0.2106738	30
Sep-12	pH	30	30	6.5	7.5	6.9766667	6.9	6.7	0.3385398	30
Oct-12	pH	30	30	6.5	7.5	6.9146667	6.825	6.64	0.32183454	30
Nov-12	pH	30	30	6.5	7.2	6.8043333	6.805	6.93	0.2112799	30
Jan-12	R-chlorine	30	30	0.1	0.8	0.2866667	0.2	0.2	0.18238522	30
Feb-12	R-chlorine	30	30	0.1	1.4	0.6273333	0.625	0.6	0.32842291	30
Mar-12	R-chlorine	30	30	0.1	0.7	0.235	0.2	0.2	0.11230347	30
Apr-12	R-chlorine	30	30	0.1	0.35	0.1633333	0.15	0.1	0.08297625	30
May-12	R-chlorine	30	30	0.1	0.65	0.155	0.1	0.1	0.1440486	30
Jun-12	R-chlorine	30	30	0.1	0.5	0.1533333	0.1	0.1	0.10822497	30
Jul-12	R-chlorine	30	30	0.1	1.25	0.41	0.3	0.15	0.31497126	30
Aug-12	R-chlorine	30	30	0.1	1.2	0.3133333	0.25	0.1	0.28825675	30

	TAMALE EAST DISTRIBUTION WATER QUALITY ANALYSIS									
MONTH	Parameter	Required No. of samples	Actual No. of Samples	Min	Max	Mean	Median	Modal Value	Std. Dev.	No of Samples Complying
Sep-12	R-chlorine	30	30	0.1	0.4	0.1166667	0.1	0.1	0.05622206	30
Oct-12	R-chlorine	30	30	0.1	1	0.17	0.1	0.1	0.20282488	30
Nov-12	R-chlorine	30	30	0.1	2	0.54	0.45	0.1	0.4613324	30
Jan-12	Turbidity	30	30	0.72	5.88	2.059	1.805		1.12355762	29
Feb-12	Turbidity	30	30	0.58	8.23	1.9473333	1.41	1.41	1.64591225	28
Mar-12	Turbidity	30	30	0.65	2.76	1.255	1.135	1.8	0.43286336	30
Apr-12	Turbidity	30	30	0	4	1.5826667	1.355	2	1.15012123	30
May-12	Turbidity	30	30	1	9	3.6666667	4	4	1.70866621	27
Jun-12	Turbidity	30	30	0.67	7.19	2.5583333	2.06	1.38	1.61242607	27
Jul-12	Turbidity	30	30	0.97	28.9	5.248	3.955	4.1	5.23119318	21
Aug-12	Turbidity	30	30	0.78	12.8	3.2023333	2.845		2.41314744	27
Sep-12	Turbidity	30	30	0.6	4.98	1.9246667	1.515	1.45	1.1140474	30
Oct-12	Turbidity	30	30	0.43	7.3	1.8823333	1.44	1.1	1.42071056	29
Nov-12	Turbidity	30	30	0.46	15.1	4.0846667	2.405		3.44431739	21

	TAMALE WEST DISTRIBUTION WATER QUALITY ANALYSIS									
MONTH	Parameter	Required No. of samples	Actual No. of Samples	Min	Max	Mean	Median	Modal Value	Std. Dev.	No of Samples Complying
Jan-12	Colour	30	30	0.7	5.4	2.8	2.65	1.9	1.280625	30
Feb-12	Colour	30	30	0	2.6	1.266667	1.1	0.9	0.748946	30
Mar-12	Colour	30	30	0.5	4.1	2.386667	2.25	3.3	0.970863	30
Apr-12	Colour	30	30	0	1.7	0.62	0.6	0.6	0.528107	30
May-12	Colour	30	30	0	5	2.21	2.05	1.9	1.400579	30
Jun-12	Colour	30	30	0	3.6	1.343333	1.4	0	1.072761	30
Jul-12	Colour	30	30	0	4.1	1.25	1.05	1.4	0.961231	30
Aug-12	Colour	30	30	0	2.9	1.17	1.05	0.9	0.758015	30
Sep-12	Colour	30	30	0	2.8	1.08	1.05	1	0.671283	30
Oct-12	Colour	30	30	0	1.8	0.44	0.2	0	0.541772	30
Nov-12	Colour	30	30	0	3.8	1.496667	1.4	0	1.092445	30
Jan-12	E-coli	30	30	0	0	0	0	0	0	30
Feb-12	E-coli	30	30	0	0	0	0	0	0	30
Mar-12	E-coli	30	30	0	0	0	0	0	0	30
Apr-12	E-coli	30	30	0	0	0	0	0	0	30
May-12	E-coli	30	30	0	0	0	0	0	0	30
Jun-12	E-coli	30	30	0	0	0	0	0	0	30
Jul-12	E-coli	30	30	0	0	0	0	0	0	30
Aug-12	E-coli	30	30	0	0	0	0	0	0	30
Sep-12	E-coli	30	30	0	0	0	0	0	0	30
Oct-12	E-coli	30	30	0	0	0	0	0	0	30
Nov-12	E-coli	30	30	0	0	0	0	0	0	30
Jan-12	pH	30	30	6.89	7.1	7.020333	7.03	7.03	0.04214	30
Feb-12	pH	30	30	6.84	7.02	6.963333	6.97	6.97	0.04467	30
Mar-12	pH	30	30	6.78	6.95	6.885333	6.89	6.87	0.038393	30
Apr-12	pH	30	30	7.11	8.14	7.512	7.645	7.65	0.255227	30
May-12	pH	30	30	6.8	7.9	7.391333	7.4	7.4	0.263945	30
Jun-12	pH	30	30	6.6	7.8	7.313333	7.4	7.6	0.319194	30
Jul-12	pH	30	30	6.5	7.4	6.692	6.615	6.6	0.195473	30
Aug-12	pH	30	30	6.5	7.8	6.774	6.8	6.5	0.255877	30
Sep-12	pH	30	30	6.5	7.5	6.703333	6.7	6.5	0.222421	30
Oct-12	pH	30	30	6.5	7.3	6.854333	6.87	6.67	0.236289	30
Nov-12	pH	30	30	6.5	7.6	6.846333	6.9	6.9	0.224906	30
Jan-12	R-chlorine	30	30	0.1	0.7	0.46	0.45	0.4	0.16938	30
Feb-12	R-chlorine	30	30	0.1	1.25	0.451667	0.2	0.2	0.433407	30
Mar-12	R-chlorine	30	30	0.15	0.25	0.198333	0.2	0.2	0.038245	30
Apr-12	R-chlorine	30	30	0.1	0.25	0.148333	0.15	0.15	0.03592	30
May-12	R-chlorine	30	30	0.1	0.25	0.153333	0.15	0.15	0.039246	30
Jun-12	R-chlorine	30	30	0.1	0.25	0.145	0.15	0.15	0.037943	30
Jul-12	R-chlorine	30	30	0.1	0.5	0.318333	0.25	0.25	0.136131	30
Aug-12	R-chlorine	30	30	0.1	0.6	0.255	0.2	0.1	0.17037	30

	TAMALE WEST DISTRIBUTION WATER QUALITY ANALYSIS									
MONTH	Parameter	Required No. of samples	Actual No. of Samples	Min	Max	Mean	Median	Modal Value	Std. Dev.	No of Samples Complying
Sep-12	R-chlorine	30	30	0.1	0.9	0.234667	0.15	0.1	0.198229	30
Oct-12	R-chlorine	30	30	0.1	1	0.168333	0.1	0.1	0.184056	30
Nov-12	R-chlorine	30	30	0.1	1.4	0.701667	0.75	0.75	0.329441	30
Jan-12	Turbidity	30	30	0.59	5.64	3.035667	2.56	2.34	1.255151	27
Feb-12	Turbidity	30	30	1.06	3.74	1.782	1.59	1.21	0.646665	30
Mar-12	Turbidity	30	30	0.81	4.28	2.514667	2.76	1.3	0.977678	30
Apr-12	Turbidity	30	30	0.59	5	1.552333	1.555	3	0.983129	30
May-12	Turbidity	30	30	0	9	4.399	4.105	4	2.098461	22
Jun-12	Turbidity	30	30	1.19	10.4	4.165	3.405	3.8	2.186202	24
Jul-12	Turbidity	30	30	1.32	9.51	3.722333	3.12		1.841247	26
Aug-12	Turbidity	30	30	1.25	8.76	3.138333	2.96		1.48583	27
Sep-12	Turbidity	30	30	0	4.65	2.697333	2.795	2.23	1.15406	30
Oct-12	Turbidity	30	30	0.74	5.4	2.077667	1.835	2.1	1.174249	29
Nov-12	Turbidity	30	30	0.84	10.3	4.672667	4.485	4.48	2.046792	18

Appendix E: Household Survey Data

SURVEY #	Location	Survey Date	Time	Name (gender)	PRIMARY			
					1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?
1	see map	1/4/13	14:25	Zenabu Shaibu (f)	Piped water	piped water	no	-
2	see map	1/4/13	14:40	Steven (m)	piped water	piped water	yes	boil, then filter with ceramic filter (PHW)
3	see map	1/7/13	9:05	Hajja Zakaria (f)	sachet water	piped water	no	-
4	see map	1/7/13	9:20	Rebecca (f)	piped water	piped water	no	-
5	see map	1/7/13	9:35	Rashida (f)	Sachet water	piped water	no	-
6	see map	1/7/13	9:55	Mary & Richard (f & m)	sachet water or tap water	piped water	no for sachet, yes for piped	pour through Pure Home Water ceramic filter
7	see map	1/7/13	10:15	no name	piped water	piped water	no except for small children	boil
8	see map	1/7/13	10:35	David Attanyiarko (f)	sachet water	piped water	no, even when occasionally drinking tap water	
9	see map	1/7/13	10:55	Kadija (f)	sachet water (sometimes piped water if it runs out)	piped water	no, even when occasionally drinking tap water	
10	see map	1/7/13	11:15	Jawwad	Piped water	piped water	no	

SURVEY #	SECONDARY				6. Do you store water?
	1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?	
1	water from "dump"	water from "dump"	yes	boil	yes, about 20 jerry cans
2	"waterways substation" (GWCL)	same as drinking	yes	boil, then filter with ceramic filter (PHW)	yes, 2 large tanks
3					yes, 500 gallon poly tank
4	sachet water	water from "waterways substation"	no	-	yes, 1 large tank
5					yes, 3 tanks
6	tanker water	tanker water	yes	pour through Pure Home Water ceramic filter	yes, 2 large poly tanks
7					yes, 2 tanks
8					yes, 1 small tank
9					yes, 1 big tank
10	"waterway substation" (GWCL)	same	no		yes, 3 small tanks

SURVEY #	6a. Do you clean your storage vessel?	6b. If yes, how often?	6c. What do you clean it with?	7. When is the water on?	7a. If the water is off for a long time do you use a secondary source?
1	yes	-	-	this week OK, on every day except for a couple hours. Sometimes off for a week to a month, especially in dry season.	yes, see secondary
2	-	-	-	during dry season can go 1 month without water	yes, see secondary
3	yes	every 3 months	brush	lately, water has been on 24 hours a day. Sometimes off for 2 weeks when GWCL has problems.	not necessary yet
4	yes	1/year	brush	sometimes on 2x a week. sometimes a month without water	yes, see secondary
5	yes	2/year	Ommo laundry soap and brush	lately, water has been on 24 hours a day. Sometimes off for up to a month.	no
6	yes	every 3 months	powdered soap and brushes	can sometimes go 1-2 weeks without water	yes, see secondary
7	not yet	will clean when it is empty	brush	lately frequent flow, sometimes up to a month without water	
8	yes	3 times a year	Ommo laundry soap and brush	since December it has been running every day in the morning, not usually in the afternoon, a little in the evening	
9	not yet	will clean when it is empty		once a week on. Sometimes 2x, never a long time off in the last year (since she lived in the house)	
10	yes	every 2 months	Ommo laundry soap and brush	flowing 4x a week usually. A month ago had no water for a month.	yes, see secondary

SURVEY #	9. Have you seen any pipe breaks in your area recently?	Sample source	Free Chlorine (mg/L)	Total Coliform (MPN)	E. Coli (MPN)	NOTES
1	no	storage	0.03	-	-	
2	no	storage	0.03	-	-	
3	no	flowing pipe	0.72	-	-	
4	yes, last month	storage (?)	0.22	-	-	
5	no	storage	0.03	0	0	
6	yes, 2 weeks ago	storage	0.06	96	0	
7	yes, 2 weeks ago	storage	0.5	-	-	
8	No	storage	0.16			
9	No	storage	0.11			
10		flowing pipe	0.1			

SURVEY #	Location	Survey Date	Time	Name (gender)	PRIMARY			
					1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?
11	see map	1/8/13	10:00	No name	sachet water (Aqua-ba)	piped water	no	
12	see map	1/8/13	10:20	Ladies Salon (f)	piped water	piped water	no	
13	Baobab Microfinance	1/8/13	10:40	Baobab Microfinance Manager (m)	sachet water	piped water	no, even when occasionally drinking tap water	
14	see map	1/8/13	10:55	Kwame (m)	piped water	piped water	no	
15	see map	1/8/13	11:10	Daniel	piped water	piped water	yes	plastic filter
SSNIT 1	Detached house #5B	1/14/13	4:00 PM	Georgina (f)	piped water	piped water	no	
SSNIT 2	Detached house	1/14/13	4:30 PM	Florence (f)	piped water	piped water	yes	filter - "aluminum filter"
SSNIT 3	SSNIT flats Block 5, apt. B	1/14/13	16:45	Mary (f)	piped water	piped water	no	

SURVEY #	SECONDARY				6. Do you store water?
	1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?	
11					yes, 2 big poly tanks
12	"dump" or tanker truck water (piped)	same	no		yes, 3 small open cement tanks
13					yes, big poly tank
14					yes, big poly tank and several smaller blue barrels
15	take water from office (respondent's Dad did this, respondent was unsure where exactly he got the water)		yes	plastic filter	yes, 1 big tank just for drinking, 1 big tank for washwater, several small containers
SSNIT 1	buy tanker water	same	no		yes, 2 large poly tanks
SSNIT 2	buy tanker water	same	yes	filter - "aluminum filter"	yes, 2 large poly tanks
SSNIT 3	buy tanker water (not very often)				yes, tanks inside apartment and outside

SURVEY #	6a. Do you clean your storage vessel?	6b. If yes, how often?	6c. What do you clean it with?	7. When is the water on?	7a. If the water is off for a long time do you use a secondary source?
11	not sure	not sure	not sure	usually all the time	no
12	yes	when it is empty	not sure	couple times a week, more in the morning, less in the afternoon	yes, see secondary
13	yes	not sure	rinsing with water	don't know because the tanks fill automatically when the water is on	no
14	yes	every 2 months	omo laundry soap and brush	4 times a week, couple hours in morning and evening, never in afternoon	
15	yes	small ones cleaned often, big drinking water tank will be cleaned (just moved to house).	omo laundry soap and sponges, sometimes just water if it doesn't "look dirty"	sometimes on for a week, sometimes off for a month	yes, see secondary
SSNIT 1	yes	1/ months	omo laundry soap and bush and sponge	2/week, for a couple hours each time	yes, see secondary
SSNIT 2	yes	every 2 weeks	omo and brush	every 2 to 3 days	yes, see secondary
SSNIT 3	yes	1-2 times per year	omo laundry soap and brush followed by new mop or clean towel	every 3 days/ once a week	yes, see secondary

SURVEY #	9. Have you seen any pipe breaks in your area recently?	Sample source	Free Chlorine (mg/L)	Total Coliform (MPN)	E. Coli (MPN)	NOTES
11	no	tank	0	0	0	this person was the recently hired caretaker of the house and he seemed a bit unsure of how everything ran at the house.
12		open tank	0	579.4	14.4	pipe was flowing with residual of 0.61 mg/L. tank sample taken instead. this was an employee of the hair salon, she did not actually live on site
13	no	bathroom sink (storage)	0.13	0	0	this was the bank manager, not a resident of the building
14	no	open blue barrel (covered)	0.02	325.5	0	
15		storage tank	0.01	1.0*	0	*proabably tray contamination, only big well positive
SSNIT 1	yes, last week, fixed the next day	poly tank, water not flowing	0.1	0	0	
SSNIT 2	No	tank	0.03	0	0	
SSNIT 3	No	tank	0.07	>2419	0	this sample came from the woman's drinking cup

SURVEY #	Location	Survey Date	Time	Name (gender)	PRIMARY			
					1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?
SSNIT 4	SSNIT flats Block 6, apt. D	1/14/13	5:00 PM	Freda (f)	piped water or sachet	piped water	yes	put camphor ball in to keep ants away, then boil before drinking
SSNIT 5	SSNIT flats 17E	1/17/13	10:45	Margaret (f)	piped water (need to collect from downstairs because pressure doesn't reach to 3rd floor)	piped water	yes	PHW clay filter
SSNIT 6	SSNIT flats 19C	1/17/13	#######	Zee (f)	piped water but usually sachet water	piped water	no	
SSNIT 7	SSNIT flats 3D	1/17/13	4:30 PM	Ibrahim (m)	sachet water	piped water	no	
SSNIT 8	SSNIT flats 8A	1/17/13	4:45 PM	Salifu and Safia	sachet water	piped water	no	

SURVEY #	SECONDARY				6. Do you store water?
	1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?	
SSNIT 4					yes, 2 plastic barrels in living room
SSNIT 5	lower apartments sometimes have water	same	yes	PHW filter	yes, plastic drums
SSNIT 6	tanker water	same	no		yes, one big tank outside, small one in kitchen
SSNIT 7					yes, one big tank outside, smaller one inside
SSNIT 8					yes, big galvanized steel tank outside

SURVEY #	6a. Do you clean your storage vessel?	6b. If yes, how often?	6c. What do you clean it with?	7. When is the water on?	7a. If the water is off for a long time do you use a secondary source?
SSNIT 4	yes	when it is empty (small barrels so likely fairly often)	liquid soap and sponge	recently pretty good, water every week	sometimes ask for downstairs neighbor's water (pressure doesn't reach up to her apt on the 2nd floor)
SSNIT 5	yes	when it is empty	omo laundry soap and sponge	usually 1-2 times a week, sometimes off for a month	yes, see secondary
SSNIT 6	yes	every 2 months	clean water and sponge	once a week usually, sometimes water doesn't reach to 2nd floor	yes, see secondary
SSNIT 7	no because they don't drink it			once a week for a couple hours	
SSNIT 8	yes	once every 6 months	hire someone to clean out the silt by hand - no soap	once every 2 weeks	no

SURVEY #	9. Have you seen any pipe breaks in your area recently?	Sample source	Free Chlorine (mg/L)	Total Coliform (MPN)	E. Coli (MPN)	NOTES
SSNIT 4	No	barrel in living room	0.02	866.4	0	told this woman I would come back and tell her the bacteria results!
SSNIT 5	No	tap - running slowly	0.06	172.2	0	
SSNIT 6	no	kitchen drum	0.06	1986.3	0	
SSNIT 7	no	from tap connected to outside tank	0.06	48.7	0	
SSNIT 8	yes near Gumani (not near house)	from tap connected to outside tank	0.03	0	0	50% dilution. this man was extremely well informed about the possible hazards associated with the piped water. He explained in detail how dirty water can infiltrate broken, unpressurized pipes and said that he sees broken pipes all the time around town.

SURVEY #	Location	Survey Date	Time	Name (gender)	PRIMARY			
					1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?
SSNIT 9	SSNIT flats 12E	1/17/13	5:15 PM	Pat (m)	sachet water	piped water	no	
CITY 1	Old Cemetery Area	1/18/13	9:05	Lukman (m)	piped water from public tap - no in-house connection	same	no	
CITY 2	Old Cemetery Area	1/18/13	9:20	Rahinata	piped water - in-house connection	piped water	no	
CITY 3	Old Cemetery Area	1/18/13	9:35	Falao (m)	piped water	piped water	no	
CITY 4	Old Cemetery Area	1/18/13	10:00	Rasmi and Sueba (f)	piped water	piped water	no	
CITY 5	Old Cemetery Area	1/18/13	10:20	Hawla and Adiza	sachet water or tap water	piped water	no	
CITY 6	Old Cemetery Area	1/18/13	10:45	Aoulet (f)	piped water	piped water	yes	boil
CITY 7	Old Cemetery Area	1/18/13	11:00	Amama (f)	piped water - not connected in house	piped water	no	
CITY 8	Old Cemetery Area	1/18/13	11:20	Selma (f)	piped water - in-house connection	piped water	no	
B1	Bulpeilla Neighborhoo d	1/21/13	9:45	Al-Hasan (m)	sachet water - sometimes piped	piped water	no	

SURVEY #	SECONDARY				6. Do you store water?
	1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?	
SSNIT 9	sachet water	"other areas near by"	no		yes, big galvanized steel tank outside
CITY 1					drum and jerry cans
CITY 2					yes, cement tank
CITY 3					yes, clay pots and oil drums
CITY 4	well nearby	same	didn't ask		yes, poly tank and jerry cans
CITY 5					yes, plastic drums
CITY 6					yes, big drums and jerry cans and clay pots
CITY 7	well - far away	same	didn't ask		yes, two big drums
CITY 8					yes, one cement tank plus smaller vessels
B1					yes, clay pots

SURVEY #	6a. Do you clean your storage vessel?	6b. If yes, how often?	6c. What do you clean it with?	7. When is the water on?	7a. If the water is off for a long time do you use a secondary source?
SSNIT 9	yes	every 2 months	omo laundry soap and brush	once a week now, in December 2012 it was off for the whole month	yes, see secondary
CITY 1	yes	when they are empty	omo laundry soap and sponge	usually twice a day, mostly mornings	
CITY 2	yes	once a week, or when tank is empty	omo laundry soap and brush	every 3 days	
CITY 3	No			1-2 times per week	
CITY 4	didn't ask			most days, not all day though	yes, see secondary
CITY 5	yes	when they are empty	omo laundry soap and brush	sometimes every day, sometimes every 1-2 weeks	
CITY 6	yes	once a week	soap other than omo - says omo causes water to taste like soap	once a week	
CITY 7	yes	every 2-3 weeks	omo laundry soap and sponge	not often, every 1-2 weeks	yes, see secondary
CITY 8	yes	once a week	soap and sponge (not omo)	4-5 days per week	
B1	yes	once a week	"silver shine" soap	every day - have to go to public tap	

SURVEY #	9. Have you seen any pipe breaks in your area recently?	Sample source	Free Chlorine (mg/L)	Total Coliform (MPN)	E. Coli (MPN)	NOTES
SSNIT 9	no	from tap connected to outside tank	0.07	0	0	
CITY 1	yes - yesterday, fixed now	drum in house	0.03	4.1	0	
CITY 2	no	from tank	0.08	108.1	5.2	
CITY 3	no	from clay pot	0.04	>2419	3.1	
CITY 4	No	from tank	0.07	6.2	0	50% dilution
CITY 5		from drum	0.06	0	0	50% dilution, could have been positive without dilution
CITY 6	No	from drum	0.06	1732.8	0	50% dilution
CITY 7	yes	from drum	0.06	>(2419*2)	0	50% dilution
CITY 8	No	from cement tank	0.06	176	2	50% dilution
B1	Yes, fixed pretty quickly	clay pot	0.17	1986.3	3.1	

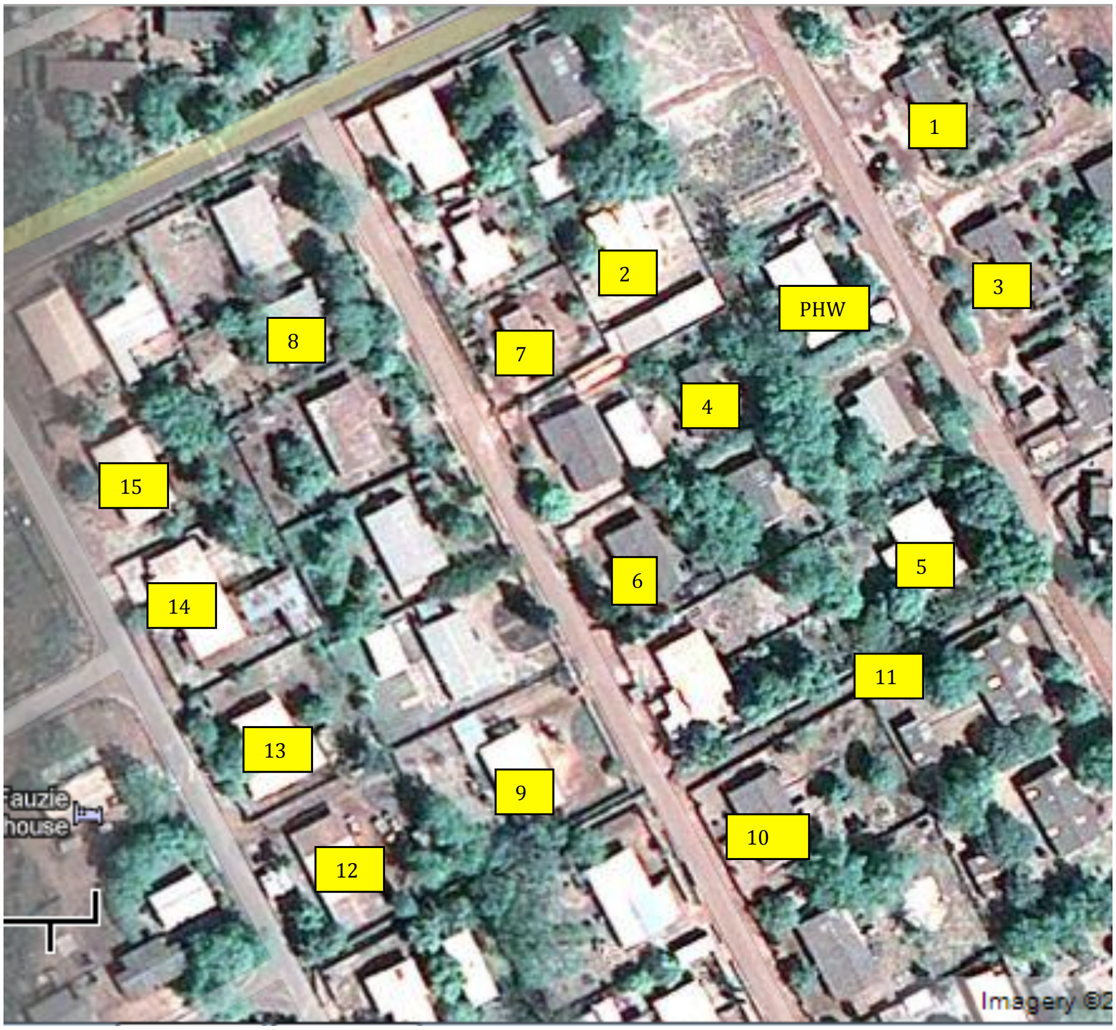
SURVEY #	Location	Survey Date	Time	Name (gender)	PRIMARY			
					1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?
B2	Bulpeilla Neighborhood	1/21/13	10:00	Arimiyaw (m)	piped water - not connected in house	piped water	no - "put in fridge"	
B3	Bulpeilla Neighborhood	1/21/13	10:15	Nuhu	piped water - not connected in house	piped water	no	
B4	Bulpeilla Neighborhood	1/21/13	10:35	Azira (f)	piped water - connected in compound	piped water	No	
B5	Bulpeilla Neighborhood	1/21/13	10:50	Fatah Idris (m)	piped water - next door connected	piped water	No - keep it covered for guinea worm	
B6	Bulpeilla Neighborhood	1/21/13	11:05	Idris (m)	piped water or sachet water - no connection in house	piped water	No	
B7 piped	Bulpeilla Neighborhood	1/21/13	11:20	Haruna (m)	piped water - not connected in house	"borehole" - unprotected dug well	no	
B7 borehole	Bulpeilla Neighborhood	1/21/13						
B8	Bulpeilla Neighborhood	1/21/13	11:35	Mary (f)	piped water - next door connected	piped water	no	

SURVEY #	SECONDARY				6. Do you store water?
	1. What do you use for drinking water?	1a. What do you use for cleaning and other purposes?	4. Do you treat the water before drinking it?	5. What do you do to treat the water?	
B2					yes, one large clay pot
B3					yes, clay pots and metal drums
B4					yes, clay pots and metal drums
B5					yes, clay pots and metal drums
B6					yes, big metal drums
B7 piped	dug well	same	yes	filter	yes, metal drums and clay pots
B7 borehole					
B8					yes, jerry cans

SURVEY #	6a. Do you clean your storage vessel?	6b. If yes, how often?	6c. What do you clean it with?	7. When is the water on?	7a. If the water is off for a long time do you use a secondary source?
B2	yes	every 3 days	omo laundry soap and brush	"always running"	
B3	yes	when it is empty	omo laundry soap and sponge	twice a week	
B4	yes	when it is empty	omo laundry soap and brush	3 days on, 3 days off	
B5	yes	when it is empty	omo laundry soap and brush	twice a week usually, sometimes always on, sometimes off for a week	
B6	yes	when it is empty	omo laundry soap and brush	1-2 times per week	
B7 piped	yes	when it is empty	water and broom	sometimes weekly, in the dry season sometimes monthly	yes, see secondary
B7 borehole					
B8	yes	when it is empty	sponge and soap	once a week or once every 2 weeks	

SURVEY #	9. Have you seen any pipe breaks in your area recently?	Sample source	Free Chlorine (mg/L)	Total Coliform (MPN)	E. Coli (MPN)	NOTES
B2	No	from clay pot	0.12	2419.6	6.3	
B3	No	clay pot	0.1	235.9	3	
B4	No	drum	0.12	<1	<1	also collected from flowing tap - Cl2 = 0.39 mg/L
B5	No	storage	0.11	90.8	17.5	
B6	yes, 2 weeks ago, fixed now	metal drum	0.04	69.1	<1	
B7 piped		metal drum - piped water storage	0.11	1986.3	93.3	
B7 borehole		metal drum - borehole storage	N/A	2419600	365400	1000:1 dilution
B8	no	jerry can	0.04	>2419.6	65	

Appendix F: Kalpohin Estates Survey Locations



Appendix G: GWCL Pressure and Flow Data

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/4/13	16:45:00	7.156875891	22.40625
5/4/13	17:00:00	7.351113574	21.65625
5/4/13	17:15:00	7.318740871	21.46875
5/4/13	17:30:00	7.351113574	21.125
5/4/13	17:45:00	7.415858685	20.96875
5/4/13	18:00:00	7.351113574	21.3125
5/4/13	18:15:00	7.383486178	21.0625
5/4/13	18:30:00	7.124502602	21.09375
5/4/13	18:45:00	5.764736076	19.96875
5/4/13	19:00:00	1.49006035	2.90625
5/4/13	19:15:00	-0.194370963	1.59375
5/4/13	19:30:00	-0.550726879	0.46875
5/4/13	19:45:00	-0.485934014	1.59375
5/4/13	20:00:00	0.161973112	9.21875
5/4/13	20:15:00	-0.226766467	2.9375
5/4/13	20:30:00	-0.356349457	3.09375
5/4/13	20:45:00	-0.485934014	2.25
5/4/13	21:00:00	-0.518330398	2.25
5/4/13	21:15:00	-0.647916912	1.4375
5/4/13	21:30:00	-0.647916912	1.03125
5/4/13	21:45:00	-0.680313785	2.53125
5/4/13	22:00:00	-0.291557766	0.84375
5/4/13	22:15:00	-0.032394916	0.25
5/4/13	22:30:00	0.097184161	0.0625
5/4/13	22:45:00	0.194367441	0
5/4/13	23:00:00	0.259155805	0
5/4/13	23:15:00	0.323943777	0
5/4/13	23:30:00	0.388731358	0
5/4/13	23:45:00	0.485911996	0.21875
5/5/13	0:00:00	0.68027063	0.875
5/5/13	0:15:00	0.809841095	0.28125
5/5/13	0:30:00	0.712663393	0.03125
5/5/13	0:45:00	0.583091753	0
5/5/13	1:00:00	0.518305346	0
5/5/13	1:15:00	0.453518548	0
5/5/13	1:30:00	0.485911996	0
5/5/13	1:45:00	0.518305346	0
5/5/13	2:00:00	0.550698599	0
5/5/13	2:15:00	0.61548481	0
5/5/13	2:30:00	0.550698599	0
5/5/13	2:45:00	0.583091753	0
5/5/13	3:00:00	0.61548481	0

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/5/13	3:15:00	0.712663393	0
5/5/13	3:30:00	0.712663393	0
5/5/13	3:45:00	0.712663393	0
5/5/13	4:00:00	0.745056058	0
5/5/13	4:15:00	0.745056058	0
5/5/13	4:30:00	0.745056058	0
5/5/13	4:45:00	0.745056058	0
5/5/13	5:00:00	0.647877769	0
5/5/13	5:15:00	0.61548481	0
5/5/13	5:30:00	0.550698599	0
5/5/13	5:45:00	0.550698599	0
5/5/13	6:00:00	0.421125002	0
5/5/13	6:15:00	0.68027063	0
5/5/13	6:30:00	2.720823589	18.75
5/5/13	6:45:00	2.979913634	5.3125
5/5/13	7:00:00	3.109456308	6.125
5/5/13	7:15:00	4.599084521	13.875
5/5/13	7:30:00	4.825748922	16
5/5/13	7:45:00	4.890509299	18.3125
5/5/13	8:00:00	4.922889341	18.59375
5/5/13	8:15:00	5.020028879	19.15625
5/5/13	8:30:00	5.117167536	19.40625
5/5/13	8:45:00	5.279063341	19.25
5/5/13	9:00:00	3.400921599	6.375
5/5/13	9:15:00	1.749180143	6.71875
5/5/13	9:30:00	0.61548481	4.5625
5/5/13	9:45:00	0.388731358	4.375
5/5/13	10:00:00	0.226761672	4
5/5/13	10:15:00	0.097184161	3.1875
5/5/13	10:30:00	0.032394818	2.625
5/5/13	10:45:00	-0.097185041	1.96875
5/5/13	11:00:00	-0.194370963	1.40625
5/5/13	11:15:00	-0.259162067	0.875
5/5/13	11:30:00	-0.291557766	0.59375
5/5/13	11:45:00	-0.226766467	0.5
5/5/13	12:00:00	2.105459633	8.6875
5/5/13	12:15:00	5.279063341	15.59375
5/5/13	12:30:00	6.509391508	14.5625
5/5/13	12:45:00	6.31513856	18.8125
5/5/13	13:00:00	6.606516661	20.5625
5/5/13	13:15:00	7.351113574	19.9375
5/5/13	13:30:00	7.869063503	19.15625
5/5/13	13:45:00	7.933805483	18.6875
5/5/13	14:00:00	8.16039933	18.375

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/5/13	14:15:00	8.419357855	18.09375
5/5/13	14:30:00	8.645941427	18.28125
5/5/13	14:45:00	8.678310117	18.40625
5/5/13	15:00:00	8.807783899	18.15625
5/5/13	15:15:00	9.001991637	17.84375
5/5/13	15:30:00	9.099094185	18
5/5/13	15:45:00	8.904888209	18.6875
5/5/13	16:00:00	8.645941427	19.375
5/5/13	16:15:00	8.548834769	19.96875
5/5/13	16:30:00	8.257509511	21.09375
5/5/13	16:45:00	8.128029074	21.9375
5/5/13	17:00:00	8.45172723	21.6875
5/5/13	17:15:00	8.354618811	21.65625
5/5/13	17:30:00	8.45172723	21.3125
5/5/13	17:45:00	8.581203753	21.28125
5/5/13	18:00:00	8.548834769	21.28125
5/5/13	18:15:00	8.484096507	21.375
5/5/13	18:30:00	8.09565872	21.6875
5/5/13	18:45:00	8.063288268	21.46875
5/5/13	19:00:00	8.354618811	21.125
5/5/13	19:15:00	8.678310117	20.625
5/5/13	19:30:00	8.872520203	20.5
5/5/13	19:45:00	8.969623926	20.40625
5/5/13	20:00:00	9.099094185	20.40625
5/5/13	20:15:00	9.196195852	20.4375
5/5/13	20:30:00	9.358030007	20.125
5/5/13	20:45:00	9.422762984	20.09375
5/5/13	21:00:00	9.519861716	20.25
5/5/13	21:15:00	9.131461505	21
5/5/13	21:30:00	8.7754156	21.90625
5/5/13	21:45:00	8.7754156	21.4375
5/5/13	22:00:00	8.872520203	20.375
5/5/13	22:15:00	8.613572638	18.96875
5/5/13	22:30:00	6.412265474	11.09375
5/5/13	22:45:00	2.656050099	5.15625
5/5/13	23:00:00	1.230934294	6.59375
5/5/13	23:15:00	0.323943777	5.34375
5/5/13	23:30:00	-0.259162067	7.09375
5/5/13	23:45:00	-0.356349457	6.5625
5/6/13	0:00:00	-0.356349457	6.9375
5/6/13	0:15:00	-0.291557766	7.21875
5/6/13	0:30:00	-0.291557766	7.46875
5/6/13	0:45:00	-0.194370963	7
5/6/13	1:00:00	-0.06478993	6.65625

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/6/13	1:15:00	0	6.875
5/6/13	1:30:00	0.097184161	7.15625
5/6/13	1:45:00	0.259155805	8.0625
5/6/13	2:00:00	0.388731358	8.5
5/6/13	2:15:00	0.453518548	8.5625
5/6/13	2:30:00	0.550698599	8.71875
5/6/13	2:45:00	0.61548481	8.84375
5/6/13	3:00:00	0.745056058	8.84375
5/6/13	3:15:00	0.842233467	8.625
5/6/13	3:30:00	0.907017916	8.46875
5/6/13	3:45:00	0.939409994	8.5
5/6/13	4:00:00	0.939409994	8.625
5/6/13	4:15:00	0.87462574	8.78125
5/6/13	4:30:00	0.809841095	8.78125
5/6/13	4:45:00	0.647877769	8.125
5/6/13	5:00:00	0.388731358	6.40625
5/6/13	5:15:00	0.129578685	5.40625
5/6/13	5:30:00	0.61548481	4.34375
5/6/13	5:45:00	4.663846268	11.875
5/6/13	6:00:00	6.088505668	14.375
5/6/13	6:15:00	5.408578223	18.0625
5/6/13	6:30:00	5.214305312	18.0625
5/6/13	6:45:00	4.793368587	17.28125
5/6/13	7:00:00	4.534322382	17.15625
5/6/13	7:15:00	4.5667035	16.96875
5/6/13	7:30:00	4.955269285	17.15625
5/6/13	7:45:00	5.084788081	16.625
5/6/13	8:00:00	5.181926151	15.625
5/6/13	8:15:00	5.570469624	16.6875
5/6/13	8:30:00	5.894245087	17
5/6/13	8:45:00	6.120882089	17.65625
5/6/13	9:00:00	6.606516661	17.625
5/6/13	9:15:00	6.962634686	17.5
5/6/13	9:30:00	7.059755729	18.15625
5/6/13	9:45:00	7.318740871	17.96875
5/6/13	10:00:00	7.869063503	17.34375
5/6/13	10:15:00	8.257509511	16.59375
5/6/13	10:30:00	8.678310117	15.625
5/6/13	10:45:00	9.066726767	14.9375
5/6/13	11:00:00	9.325663372	14.21875
5/6/13	11:15:00	9.519861716	13.96875
5/6/13	11:30:00	9.714056537	13.5
5/6/13	11:45:00	9.778787361	13.3125
5/6/13	12:00:00	9.746421998	14.34375

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/6/13	12:15:00	9.811152626	14.6875
5/6/13	12:30:00	10.03770674	14.34375
5/6/13	12:45:00	10.32898356	13.5625
5/6/13	13:00:00	10.29661986	13.75
5/6/13	13:15:00	10.1347999	14.375
5/6/13	13:30:00	10.16716409	15
5/6/13	13:45:00	10.16716409	15.78125
5/6/13	14:00:00	9.455129326	18
5/6/13	14:15:00	8.8401521	20.09375
5/6/13	14:30:00	8.710678709	20.6875
5/6/13	14:45:00	8.678310117	21.03125
5/6/13	15:00:00	8.645941427	21.5625
5/6/13	15:15:00	8.45172723	21.59375
5/6/13	15:30:00	7.674835215	22.90625
5/6/13	15:45:00	6.638891516	25.09375
5/6/13	16:00:00	6.250386794	25.21875
5/6/13	16:15:00	4.85812916	22.21875
5/6/13	16:30:00	0.777448625	3.8125
5/6/13	16:45:00	-0.356349457	2.9375
5/6/13	17:00:00	-0.453537728	2.3125
5/6/13	17:15:00	-0.032394916	7.46875
5/6/13	17:30:00	-0.129580251	5.09375
5/6/13	17:45:00	-0.097185041	2.96875
5/6/13	18:00:00	3.109456308	10.25
5/6/13	18:15:00	5.279063341	15.5625
5/6/13	18:30:00	5.861867981	17.59375
5/6/13	18:45:00	6.185634638	18.71875
5/6/13	19:00:00	5.861867981	21.875
5/6/13	19:15:00	5.311442208	20.34375
5/6/13	19:30:00	2.429339803	2.875
5/6/13	19:45:00	0.87462574	2.75
5/6/13	20:00:00	0.388731358	4.5
5/6/13	20:15:00	-0.129580251	3.5625
5/6/13	20:30:00	-0.518330398	2.53125
5/6/13	20:45:00	-0.38874545	6.0625
5/6/13	21:00:00	-0.485934014	4.09375
5/6/13	21:15:00	-0.647916912	1.5
5/6/13	21:30:00	-0.583123459	2.28125
5/6/13	21:45:00	-0.583123459	3.5
5/6/13	22:00:00	-0.583123459	2.5625
5/6/13	22:15:00	-0.615520136	2.65625
5/6/13	22:30:00	-0.583123459	1.5625
5/6/13	22:45:00	-0.550726879	0.71875
5/6/13	23:00:00	-0.550726879	1.6875

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/6/13	23:15:00	-0.550726879	1
5/6/13	23:30:00	-0.583123459	0.1875
5/6/13	23:45:00	-0.518330398	0.625
5/7/13	0:00:00	-0.550726879	0.34375
5/7/13	0:15:00	-0.550726879	0.125
5/7/13	0:30:00	-0.485934014	0
5/7/13	0:45:00	-0.485934014	0
5/7/13	1:00:00	-0.42114154	0
5/7/13	1:15:00	-0.291557766	1.875
5/7/13	1:30:00	-0.259162067	0.21875
5/7/13	1:45:00	-0.161975558	0.0625
5/7/13	2:00:00	0.032394818	0
5/7/13	2:15:00	0.712663393	2.4375
5/7/13	2:30:00	1.036585641	2.90625
5/7/13	2:45:00	1.166151801	0.125
5/7/13	3:00:00	1.133760408	1.09375
5/7/13	3:15:00	1.068977328	0.71875
5/7/13	3:30:00	1.036585641	0.375
5/7/13	3:45:00	0.971801975	0.25
5/7/13	4:00:00	0.939409994	0.3125
5/7/13	4:15:00	0.87462574	0.59375
5/7/13	4:30:00	0.745056058	0.1875
5/7/13	4:45:00	0.550698599	0.125
5/7/13	5:00:00	2.656050099	8.875
5/7/13	5:15:00	7.415858685	12.9375
5/7/13	5:30:00	8.613572638	13.65625
5/7/13	5:45:00	8.484096507	15.28125
5/7/13	6:00:00	7.318740871	18.1875
5/7/13	6:15:00	6.023752533	20.46875
5/7/13	6:30:00	5.279063341	21.53125
5/7/13	6:45:00	4.922889341	22.6875
5/7/13	7:00:00	4.793368587	23
5/7/13	7:15:00	4.372415324	20.21875
5/7/13	7:30:00	4.048593868	18
5/7/13	7:45:00	4.340033619	17.90625
5/7/13	8:00:00	4.663846268	17.375
5/7/13	8:15:00	4.955269285	17.6875
5/7/13	8:30:00	4.922889341	17.625
5/7/13	8:45:00	4.696226994	18.15625
5/7/13	9:00:00	4.501941166	18.6875
5/7/13	9:15:00	3.141841731	15.5
5/7/13	9:30:00	4.534322382	23.96875
5/7/13	9:45:00	5.214305312	22.28125
5/7/13	10:00:00	5.602847611	20.6875

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/7/13	10:15:00	4.145741332	11.3125
5/7/13	10:30:00	0.842233467	4.25
5/7/13	10:45:00	-0.291557766	3.21875
5/7/13	11:00:00	-0.259162067	5.15625
5/7/13	11:15:00	-0.129580251	6.78125
5/7/13	11:30:00	-0.291557766	4.46875
5/7/13	11:45:00	-0.38874545	4.3125
5/7/13	12:00:00	-0.518330398	3.3125
5/7/13	12:15:00	-0.194370963	0.59375
5/7/13	12:30:00	-0.06478993	0.125
5/7/13	12:45:00	-0.032394916	0.03125
5/7/13	13:00:00	0.097184161	0.03125
5/7/13	13:15:00	0.226761672	0.03125
5/7/13	13:30:00	0.29154984	0
5/7/13	13:45:00	0.259155805	0
5/7/13	14:00:00	0.259155805	0
5/7/13	14:15:00	0.29154984	0
5/7/13	14:30:00	0.259155805	0
5/7/13	14:45:00	0.259155805	0
5/7/13	15:00:00	0.29154984	0
5/7/13	15:15:00	0.29154984	0
5/7/13	15:30:00	0.259155805	0
5/7/13	15:45:00	0.259155805	0
5/7/13	16:00:00	0.29154984	0
5/7/13	16:15:00	0.259155805	0
5/7/13	16:30:00	0.259155805	0
5/7/13	16:45:00	0.259155805	0
5/7/13	17:00:00	0.29154984	0
5/7/13	17:15:00	0.323943777	0
5/7/13	17:30:00	0.259155805	0
5/7/13	17:45:00	0.29154984	0
5/7/13	18:00:00	0.29154984	0
5/7/13	18:15:00	0.29154984	0
5/7/13	18:30:00	0.323943777	0
5/7/13	18:45:00	0.323943777	0
5/7/13	19:00:00	0.323943777	0
5/7/13	19:15:00	0.388731358	0
5/7/13	19:30:00	0.421125002	0
5/7/13	19:45:00	0.421125002	0
5/7/13	20:00:00	0.421125002	0
5/7/13	20:15:00	0.421125002	0
5/7/13	20:30:00	0.453518548	0
5/7/13	20:45:00	0.453518548	0
5/7/13	21:00:00	0.453518548	0

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/7/13	21:15:00	0.485911996	0
5/7/13	21:30:00	0.485911996	0
5/7/13	21:45:00	0.583091753	0
5/7/13	22:00:00	3.206612285	7.9375
5/7/13	22:15:00	5.343820978	14.125
5/7/13	22:30:00	5.214305312	17.40625
5/7/13	22:45:00	5.117167536	18.4375
5/7/13	23:00:00	5.311442208	18.1875
5/7/13	23:15:00	5.505713357	20.3125
5/7/13	23:30:00	6.412265474	19.59375
5/7/13	23:45:00	6.93026081	19.78125
5/8/13	0:00:00	7.351113574	19.40625
5/8/13	0:15:00	7.739578369	19.21875
5/8/13	0:30:00	7.966176326	18.625
5/8/13	0:45:00	8.192769488	18.65625
5/8/13	1:00:00	8.386988382	18.71875
5/8/13	1:15:00	8.548834769	19.28125
5/8/13	1:30:00	8.678310117	19.78125
5/8/13	1:45:00	9.001991637	19
5/8/13	2:00:00	9.293296639	18.4375
5/8/13	2:15:00	9.422762984	18.34375
5/8/13	2:30:00	9.422762984	18.59375
5/8/13	2:45:00	9.584593714	18.25
5/8/13	3:00:00	9.714056537	17.96875
5/8/13	3:15:00	9.228562879	18.90625
5/8/13	3:30:00	8.937256116	19.03125
5/8/13	3:45:00	8.128029074	16.625
5/8/13	4:00:00	4.178123625	7.90625
5/8/13	4:15:00	1.716790511	13.71875
5/8/13	4:30:00	0.583091753	14.84375
5/8/13	4:45:00	-0.097185041	11.375
5/8/13	5:00:00	-0.323953563	6.59375
5/8/13	5:15:00	-0.518330398	1.03125
5/8/13	5:30:00	1.716790511	8.46875
5/8/13	5:45:00	3.238997416	20.78125
5/8/13	6:00:00	3.659995204	19.5
5/8/13	6:15:00	3.821913026	16.78125
5/8/13	6:30:00	3.983828402	13.90625
5/8/13	6:45:00	4.080976454	12.21875
5/8/13	7:00:00	3.983828402	11.5625
5/8/13	7:15:00	4.048593868	10.09375
5/8/13	7:30:00	4.145741332	10.34375
5/8/13	7:45:00	4.178123625	9.5625
5/8/13	8:00:00	4.242887916	10

SITEID1 - DMA A1_SSNIT FLATS		PRESSURE	FLOW
DATE	TIME	METRES	LITRES/SECOND
5/8/13	8:15:00	4.340033619	9.875
5/8/13	8:30:00	4.307651816	9.0625
5/8/13	8:45:00	4.404796931	9.3125
5/8/13	9:00:00	4.404796931	9.46875
5/8/13	9:15:00	4.437178441	9.6875
5/8/13	9:30:00	4.501941166	9.9375
5/8/13	9:45:00	4.5667035	10.15625
5/8/13	10:00:00	4.534322382	10.53125
5/8/13	10:15:00	4.631465443	10.59375
5/8/13	10:30:00	4.599084521	10.6875
5/8/13	10:45:00	4.599084521	10.28125
5/8/13	11:00:00	4.599084521	10.90625
5/8/13	11:15:00	4.599084521	11.15625
5/8/13	11:30:00	4.5667035	10.125

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/4/13	17:00:00	8.337553299	30.96875
5/4/13	17:15:00	7.905887123	32.625
5/4/13	17:30:00	7.80626938	33.25
5/4/13	17:45:00	8.071914635	32.28125
5/4/13	18:00:00	8.138324919	31.9375
5/4/13	18:15:00	7.905887123	33.25
5/4/13	18:30:00	7.507410592	34.28125
5/4/13	18:45:00	6.444734018	31.9375
5/4/13	19:00:00	1.628159442	25.5
5/4/13	19:15:00	0.066460327	24.625
5/4/13	19:30:00	-0.13292189	13.78125
5/4/13	19:45:00	-0.232614388	2.46875
5/4/13	20:00:00	-0.232614388	1.96875
5/4/13	20:15:00	-0.232614388	1
5/4/13	20:30:00	-0.232614388	0.3125
5/4/13	20:45:00	-0.232614388	0.09375
5/4/13	21:00:00	-0.232614388	0.03125
5/4/13	21:15:00	-0.232614388	0.03125
5/4/13	21:30:00	-0.199383452	0
5/4/13	21:45:00	-0.265845427	0
5/4/13	22:00:00	0	0
5/4/13	22:15:00	0.033230215	0
5/4/13	22:30:00	0.033230215	0
5/4/13	22:45:00	0.033230215	0
5/4/13	23:00:00	0.066460327	0
5/4/13	23:15:00	0.033230215	0
5/4/13	23:30:00	0.099690336	0
5/4/13	23:45:00	0.099690336	0
5/5/13	0:00:00	0.099690336	0
5/5/13	0:15:00	0.199379745	0
5/5/13	0:30:00	0.431984763	0
5/5/13	0:45:00	0.731040943	0.15625
5/5/13	1:00:00	1.295902084	4
5/5/13	1:15:00	1.46203205	9
5/5/13	1:30:00	1.46203205	9.9375
5/5/13	1:45:00	1.495257734	10.28125
5/5/13	2:00:00	1.528483315	11.625
5/5/13	2:15:00	1.528483315	11.84375
5/5/13	2:30:00	1.528483315	12.03125
5/5/13	2:45:00	1.528483315	12.0625
5/5/13	3:00:00	1.528483315	11.84375
5/5/13	3:15:00	1.561708794	11.40625

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/5/13	3:30:00	1.528483315	11.21875
5/5/13	3:45:00	1.561708794	11.4375
5/5/13	4:00:00	1.561708794	11.6875
5/5/13	4:15:00	1.561708794	11.8125
5/5/13	4:30:00	1.528483315	11.625
5/5/13	4:45:00	1.528483315	11.375
5/5/13	5:00:00	1.46203205	11.375
5/5/13	5:15:00	1.495257734	11.4375
5/5/13	5:30:00	1.46203205	12
5/5/13	5:45:00	1.295902084	10.21875
5/5/13	6:00:00	0.963634429	5.78125
5/5/13	6:15:00	0.697812891	3.75
5/5/13	6:30:00	1.860733466	16.3125
5/5/13	6:45:00	1.162996257	31.5625
5/5/13	7:00:00	1.063315806	32.34375
5/5/13	7:15:00	1.993630643	42.125
5/5/13	7:30:00	2.591647551	43.125
5/5/13	7:45:00	3.289291778	41.90625
5/5/13	8:00:00	3.588268261	40.9375
5/5/13	8:15:00	3.72114402	40.78125
5/5/13	8:30:00	3.887236403	40.78125
5/5/13	8:45:00	3.986890596	40.5625
5/5/13	9:00:00	2.525202875	31
5/5/13	9:15:00	1.030088783	26.21875
5/5/13	9:30:00	0.132920242	23.46875
5/5/13	9:45:00	-0.033230318	12.1875
5/5/13	10:00:00	0.199379745	10.3125
5/5/13	10:15:00	0.232609342	3.84375
5/5/13	10:30:00	0.232609342	2.96875
5/5/13	10:45:00	0.332297516	3.375
5/5/13	11:00:00	0.332297516	3.78125
5/5/13	11:15:00	0.332297516	3.53125
5/5/13	11:30:00	0.498442413	4.375
5/5/13	11:45:00	0.531671083	4.375
5/5/13	12:00:00	1.694609678	13.25
5/5/13	12:15:00	2.790979107	38.78125
5/5/13	12:30:00	3.92045457	42.90625
5/5/13	12:45:00	5.21588279	40.09375
5/5/13	13:00:00	6.345102683	37.96875
5/5/13	13:15:00	7.507410592	35.1875
5/5/13	13:30:00	8.171529906	33.40625
5/5/13	13:45:00	8.603185374	32.59375
5/5/13	14:00:00	9.03482344	31.28125
5/5/13	14:15:00	9.532845738	29.375

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	**TIME**	**METRES**	**LITRES PER SECOND**
5/5/13	14:30:00	9.36684088	30.375
5/5/13	14:45:00	9.400042057	31.46875
5/5/13	15:00:00	9.499644973	30.96875
5/5/13	15:15:00	9.831647997	30.1875
5/5/13	15:30:00	10.23003803	28.0625
5/5/13	15:45:00	10.06404399	28.125
5/5/13	16:00:00	9.732048171	29.53125
5/5/13	16:15:00	9.765248216	29.21875
5/5/13	16:30:00	9.499644973	29.3125
5/5/13	16:45:00	9.167631651	30.6875
5/5/13	17:00:00	9.36684088	29.34375
5/5/13	17:15:00	9.333639599	29.90625
5/5/13	17:30:00	9.36684088	29.78125
5/5/13	17:45:00	9.532845738	29.40625
5/5/13	18:00:00	9.234035139	31.03125
5/5/13	18:15:00	8.968418716	32.3125
5/5/13	18:30:00	8.47037016	33.40625
5/5/13	18:45:00	8.337553299	33.625
5/5/13	19:00:00	8.73599894	32.5
5/5/13	19:15:00	9.333639599	30.53125
5/5/13	19:30:00	9.499644973	30.9375
5/5/13	19:45:00	9.632447418	30.875
5/5/13	20:00:00	9.997645648	29.21875
5/5/13	20:15:00	10.19683943	28.5625
5/5/13	20:30:00	10.26323653	28.625
5/5/13	20:45:00	10.23003803	29.78125
5/5/13	21:00:00	10.59521588	28.125
5/5/13	21:15:00	10.59521588	27.0625
5/5/13	21:30:00	10.49562315	25.5625
5/5/13	21:45:00	10.59521588	24.4375
5/5/13	22:00:00	10.69480767	23.375
5/5/13	22:15:00	10.49562315	21.875
5/5/13	22:30:00	8.005503939	18.90625
5/5/13	22:45:00	3.854018132	16.125
5/5/13	23:00:00	2.624869734	14.96875
5/5/13	23:15:00	1.727834641	13.84375
5/5/13	23:30:00	1.196222868	12.84375
5/5/13	23:45:00	0.963634429	12.875
5/6/13	0:00:00	0.830724483	12.46875
5/6/13	0:15:00	0.664584735	12.15625
5/6/13	0:30:00	0.531671083	11.46875
5/6/13	0:45:00	0.199379745	10.65625
5/6/13	1:00:00	-0.13292189	10.03125
5/6/13	1:15:00	0.265838837	13.71875

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/6/13	1:30:00	0.398755784	13.71875
5/6/13	1:45:00	0.598128115	13.25
5/6/13	2:00:00	0.664584735	13.1875
5/6/13	2:15:00	0.764268893	13
5/6/13	2:30:00	0.897179662	13.21875
5/6/13	2:45:00	0.996861657	13.40625
5/6/13	3:00:00	1.063315806	13.4375
5/6/13	3:15:00	1.129769543	13.34375
5/6/13	3:30:00	1.162996257	13.375
5/6/13	3:45:00	1.162996257	13.65625
5/6/13	4:00:00	1.196222868	13.4375
5/6/13	4:15:00	1.196222868	13.3125
5/6/13	4:30:00	1.096542726	13.125
5/6/13	4:45:00	1.096542726	13.6875
5/6/13	5:00:00	1.063315806	13.59375
5/6/13	5:15:00	0.963634429	13.53125
5/6/13	5:30:00	0.897179662	13.71875
5/6/13	5:45:00	2.259420054	28.375
5/6/13	6:00:00	3.156410665	38.75
5/6/13	6:15:00	3.189631098	39.625
5/6/13	6:30:00	3.023527903	42.15625
5/6/13	6:45:00	2.757757438	41.9375
5/6/13	7:00:00	3.056748748	39.59375
5/6/13	7:15:00	3.322511799	38.59375
5/6/13	7:30:00	4.020108455	37.03125
5/6/13	7:45:00	4.053326211	37.15625
5/6/13	8:00:00	3.787581282	38.1875
5/6/13	8:15:00	4.285847617	38.1875
5/6/13	8:30:00	4.983381565	36.84375
5/6/13	8:45:00	5.71408271	34.8125
5/6/13	9:00:00	6.411523676	33.53125
5/6/13	9:15:00	6.743622462	33.90625
5/6/13	9:30:00	7.308166766	31.71875
5/6/13	9:45:00	7.374581786	32.09375
5/6/13	10:00:00	7.972298437	30.875
5/6/13	10:15:00	8.4371661	30.1875
5/6/13	10:30:00	8.835608033	29.96875
5/6/13	10:45:00	9.134429753	29.78125
5/6/13	11:00:00	9.300438215	30.46875
5/6/13	11:15:00	9.632447418	29.6875
5/6/13	11:30:00	9.765248216	29.5625
5/6/13	11:45:00	9.732048171	30.34375
5/6/13	12:00:00	9.931246896	29.65625
5/6/13	12:15:00	10.13044191	28.625

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/6/13	12:30:00	10.49562315	27.65625
5/6/13	12:45:00	10.66161051	27.8125
5/6/13	13:00:00	10.66161051	27.96875
5/6/13	13:15:00	10.66161051	27.03125
5/6/13	13:30:00	10.66161051	27.3125
5/6/13	13:45:00	10.86079194	26.875
5/6/13	14:00:00	10.39602951	28.1875
5/6/13	14:15:00	10.13044191	27.78125
5/6/13	14:30:00	10.06404399	28.15625
5/6/13	14:45:00	9.964446323	28.46875
5/6/13	15:00:00	10.097243	28.3125
5/6/13	15:15:00	9.698848023	29.5625
5/6/13	15:30:00	9.234035139	29.125
5/6/13	15:45:00	8.569981725	29.125
5/6/13	16:00:00	8.204734791	28.90625
5/6/13	16:15:00	6.411523676	28.25
5/6/13	16:30:00	1.262675781	23.75
5/6/13	16:45:00	0.099690336	24
5/6/13	17:00:00	-0.066460739	11.1875
5/6/13	17:15:00	-0.13292189	2.3125
5/6/13	17:30:00	-0.13292189	2.1875
5/6/13	17:45:00	-0.13292189	1.875
5/6/13	18:00:00	1.860733466	16.65625
5/6/13	18:15:00	2.558425265	33.875
5/6/13	18:30:00	3.72114402	35.84375
5/6/13	18:45:00	5.21588279	33.5
5/6/13	19:00:00	6.012991542	30.84375
5/6/13	19:15:00	5.846932109	28.21875
5/6/13	19:30:00	2.658091815	19.46875
5/6/13	19:45:00	1.495257734	14.625
5/6/13	20:00:00	1.395580372	13.84375
5/6/13	20:15:00	1.295902084	13.375
5/6/13	20:30:00	1.063315806	13.5625
5/6/13	20:45:00	0.365526701	13.34375
5/6/13	21:00:00	-0.066460739	3.375
5/6/13	21:15:00	0.099690336	0.84375
5/6/13	21:30:00	0.166150045	0
5/6/13	21:45:00	0.166150045	0
5/6/13	22:00:00	0.199379745	0
5/6/13	22:15:00	0.232609342	0
5/6/13	22:30:00	0.232609342	0
5/6/13	22:45:00	0.265838837	0
5/6/13	23:00:00	0.232609342	0
5/6/13	23:15:00	0.265838837	0

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/6/13	23:30:00	0.332297516	0
5/6/13	23:45:00	0.431984763	0
5/7/13	0:00:00	0.531671083	0.9375
5/7/13	0:15:00	0.664584735	2.625
5/7/13	0:30:00	0.697812891	3.25
5/7/13	0:45:00	0.697812891	3.46875
5/7/13	1:00:00	0.697812891	3.90625
5/7/13	1:15:00	0.764268893	4.34375
5/7/13	1:30:00	0.930407097	4.78125
5/7/13	1:45:00	1.030088783	5.21875
5/7/13	2:00:00	1.063315806	6.53125
5/7/13	2:15:00	1.329128283	10.46875
5/7/13	2:30:00	1.528483315	12.40625
5/7/13	2:45:00	1.561708794	12.78125
5/7/13	3:00:00	1.561708794	12.90625
5/7/13	3:15:00	1.528483315	12.875
5/7/13	3:30:00	1.528483315	12.875
5/7/13	3:45:00	1.528483315	12.90625
5/7/13	4:00:00	1.495257734	12.84375
5/7/13	4:15:00	1.495257734	12.78125
5/7/13	4:30:00	1.46203205	12.5625
5/7/13	4:45:00	1.395580372	11.59375
5/7/13	5:00:00	2.060078613	15.90625
5/7/13	5:15:00	4.485147665	34.625
5/7/13	5:30:00	7.142127412	31.0625
5/7/13	5:45:00	7.440996395	30.65625
5/7/13	6:00:00	6.378313231	34.15625
5/7/13	6:15:00	4.883736638	38
5/7/13	6:30:00	4.352281378	39.5625
5/7/13	6:45:00	4.119761413	39.46875
5/7/13	7:00:00	3.854018132	40.375
5/7/13	7:15:00	3.322511799	38.96875
5/7/13	7:30:00	2.757757438	38.625
5/7/13	7:45:00	3.123190129	37.28125
5/7/13	8:00:00	3.72114402	35.78125
5/7/13	8:15:00	4.086543863	34.875
5/7/13	8:30:00	4.285847617	34.6875
5/7/13	8:45:00	4.252630583	34.71875
5/7/13	9:00:00	4.219413445	34.03125
5/7/13	9:15:00	2.990306956	30.5625
5/7/13	9:30:00	4.850521457	34.96875
5/7/13	9:45:00	5.481592297	33.5625
5/7/13	10:00:00	5.813719914	32.09375
5/7/13	10:15:00	4.219413445	27.71875

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/7/13	10:30:00	0.963634429	24.09375
5/7/13	10:45:00	0.099690336	22.4375
5/7/13	11:00:00	-0.066460739	9.6875
5/7/13	11:15:00	-0.099691263	3.09375
5/7/13	11:30:00	0	1.15625
5/7/13	11:45:00	0.166150045	0
5/7/13	12:00:00	0.166150045	0
5/7/13	12:15:00	0.199379745	0
5/7/13	12:30:00	0.166150045	0
5/7/13	12:45:00	0.166150045	0
5/7/13	13:00:00	0.166150045	0
5/7/13	13:15:00	0.132920242	0
5/7/13	13:30:00	0.166150045	0
5/7/13	13:45:00	0.166150045	0
5/7/13	14:00:00	0.166150045	0
5/7/13	14:15:00	0.166150045	0
5/7/13	14:30:00	0.166150045	0
5/7/13	14:45:00	0.166150045	0
5/7/13	15:00:00	0.166150045	0
5/7/13	15:15:00	0.199379745	0
5/7/13	15:30:00	0.166150045	0
5/7/13	15:45:00	0.166150045	0
5/7/13	16:00:00	0.166150045	0
5/7/13	16:15:00	0.199379745	0
5/7/13	16:30:00	0.199379745	0
5/7/13	16:45:00	0.199379745	0
5/7/13	17:00:00	0.199379745	0
5/7/13	17:15:00	0.199379745	0
5/7/13	17:30:00	0.199379745	0
5/7/13	17:45:00	0.199379745	0
5/7/13	18:00:00	0.166150045	0
5/7/13	18:15:00	0.199379745	0
5/7/13	18:30:00	0.199379745	0
5/7/13	18:45:00	0.199379745	0
5/7/13	19:00:00	0.199379745	0
5/7/13	19:15:00	0.199379745	0
5/7/13	19:30:00	0.199379745	0
5/7/13	19:45:00	0.199379745	0
5/7/13	20:00:00	0.199379745	0
5/7/13	20:15:00	0.199379745	0
5/7/13	20:30:00	0.199379745	0
5/7/13	20:45:00	0.199379745	0
5/7/13	21:00:00	0.199379745	0
5/7/13	21:15:00	0.232609342	0

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/7/13	21:30:00	0.199379745	0
5/7/13	21:45:00	0.232609342	0
5/7/13	22:00:00	1.761059502	10
5/7/13	22:15:00	2.325866377	36.78125
5/7/13	22:30:00	2.790979107	40.21875
5/7/13	22:45:00	2.525202875	42.96875
5/7/13	23:00:00	3.521829763	41.375
5/7/13	23:15:00	5.116240025	36.625
5/7/13	23:30:00	6.610784183	32.59375
5/7/13	23:45:00	7.839475398	28.65625
5/8/13	0:00:00	8.47037016	27.34375
5/8/13	0:15:00	8.902013581	26.3125
5/8/13	0:30:00	9.001621129	26.40625
5/8/13	0:45:00	9.433243132	25.65625
5/8/13	1:00:00	9.798448158	24.75
5/8/13	1:15:00	10.097243	23.84375
5/8/13	1:30:00	10.19683943	23.40625
5/8/13	1:45:00	10.42922749	22.71875
5/8/13	2:00:00	10.82759529	22.28125
5/8/13	2:15:00	10.96038126	22.40625
5/8/13	2:30:00	11.05996965	22.5
5/8/13	2:45:00	11.09316558	22.90625
5/8/13	3:00:00	11.25914367	22.5625
5/8/13	3:15:00	10.96038126	22.5
5/8/13	3:30:00	10.66161051	22.875
5/8/13	3:45:00	9.798448158	21.5
5/8/13	4:00:00	5.21588279	17.0625
5/8/13	4:15:00	2.292643267	17.1875
5/8/13	4:30:00	0.830724483	18.09375
5/8/13	4:45:00	0.199379745	17.4375
5/8/13	5:00:00	-0.099691263	11.75
5/8/13	5:15:00	-0.13292189	4.96875
5/8/13	5:30:00	0.564899651	9.03125
5/8/13	5:45:00	1.46203205	33.5
5/8/13	6:00:00	1.295902084	40.34375
5/8/13	6:15:00	1.096542726	42.25
5/8/13	6:30:00	0.764268893	44.375
5/8/13	6:45:00	0.598128115	45.46875
5/8/13	7:00:00	0.631356477	45.3125
5/8/13	7:15:00	0.598128115	44.875
5/8/13	7:30:00	0.598128115	45.375
5/8/13	7:45:00	0.631356477	45.21875
5/8/13	8:00:00	0.631356477	45.4375
5/8/13	8:15:00	0.598128115	45.53125

SITEID1 - DMA C7_Old Cemetery		PRESSURE	FLOW
DATE	TIME	METRES	LITRES PER SECOND
5/8/13	8:30:00	0.598128115	45.40625
5/8/13	8:45:00	0.598128115	45.90625
5/8/13	9:00:00	0.631356477	46.09375
5/8/13	9:15:00	0.631356477	46.1875
5/8/13	9:30:00	0.631356477	46.46875
5/8/13	9:45:00	0.664584735	46.65625
5/8/13	10:00:00	0.664584735	47.03125
5/8/13	10:15:00	0.664584735	47.09375
5/8/13	10:30:00	0.664584735	47.09375
5/8/13	10:45:00	0.664584735	46.75
5/8/13	11:00:00	0.697812891	46.90625
5/8/13	11:15:00	0.697812891	47.09375
5/8/13	11:30:00	0.664584735	46.8125